MACHINE TOOL OPERATION

PART II

Drilling · Planing · Milling · Grinding

HENRY D. BURGHARDT

MACHINE TOOL OPERATION

Books by

HENRY D. BURGHARDT

MACHINE TOOL OPERATION

PART I

The Lathe, Benchwork and Work at the Forge

401 pages, 5 × 7½, 254 illustrations

PART II

Drilling Machine, Shaper and Planer, Milling and Grinding Machines, Hydraulic Power Transmission, Gears

512 pages, 5 × 7½, 353 illustrations

MACHINE TOOL OPERATION

PART II

DRILLING MACHINE
SHAPER AND PLANER
MILLING AND GRINDING MACHINES
HYDRAULIC POWER TRANSMISSION
SPUR GEARS AND BEVEL GEARS

BY

HENRY D. BURGHARDT

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PREFACE TO THE SECOND EDITION

While holding to the general plan of the old edition, this revision provides many improvements in the presentation that will make for clearness. The aim has been to make this edition more comprehensive and more interesting, and also easier to understand.

Much new material has been added. New cuts and descriptions serve better to show the shaper drive and the modern cam-action feeding mechanism; there is an entirely new discussion of laying out and leveling planer work; differential indexing is included in milling-machine work; the chapters on grinding wheels and grinding operations have been entirely rewritten with additional information about wheel selection, centerless grinding, and hand lapping; and the discussion of spur and bevel gears now includes the new standard terminology.

A chapter on the hydraulic drive of machine tools has been added. It is believed that this descriptive material, together with the twenty illustrations of pumps, valves, and circuits, will give the student a valuable introduction to this recent development in machine-tool construction and operation.

The book as a whole has been enlarged considerably as to text content and illustrations.

Acknowledgments appear throughout the book, but the author wishes to express his appreciation and thanks for the assistance given by the many manufacturing concerns, and for the courtesy and cooperation shown by their representatives. He is especially indebted to the following individuals and manufacturers: Elmer H. Neff, Brown & Sharpe Mfg. Co.; R. N. Piper, Cincinnati Bickford Tool Co.; J. C. Hussey, American Tool Works Co.; F. J. McCarty, Hendey Machine Co.; August Marx, G. A. Gray Co.; Harold Dunbar, Norton Co.; E. C. Shultz, Pratt & Whitney Co.; M. E. Engebretson, Oilgear Co.; and L. R. Twyman, Vickers, Inc.

Jersey City, N. J.,
June, 1937.

H. D. B.

PREFACE TO THE FIRST EDITION

The preface of Part I gives the reasons for preparing this text. Part I deals with lathe work, bench work, and work at the forge. An attempt has been made in this volume (Part II) to organize the *fundamental principles of construction and operation* of the Drilling Machine, Shaper, Planer, Milling Machine, and Grinding Machine. Chapters embodying what every machinist should know concerning spur gears and bevel gears are included.

Only fundamentally has this work anything to do with production. Special rapid-production machines and tools represent various combinations of fundamental mechanisms, methods and processes. The purpose of this text is to discuss these fundamentals, and build a foundation for rapid production; the same sort of foundation that arithmetic builds for mathematical calculations.

Perhaps a statement regarding the way in which the following text is presented and the reasons therefore should be made here:

First: While there are a great many sizes, types, and kinds of each of the standard machine tools, and while the makers differ in details of design, the fact remains that the primary function, and the basic principles of construction and operation of the given class of machine, are the same regardless of the size or where it is made. Therefore, a well-known example of each of the machine tools under discussion has been selected and described, and typical mechanisms illustrated and explained in such a way as to bring out the general details.

Second: The operator's production, interest and progress are in proportion to his understanding of the basic principles of the construction of the machine he is running—the special mechanical features, feed changes, speed changes, and adjustments of the machine. Consequently, these things have been discussed early in the study of the particular machine.

Third: The broader the student's knowledge concerning the cutting tools used in the given machine, and the quicker he gets a fairly comprehensive idea of the shapes, sizes and characteristics of these tools, the easier and better he can "run the machine." Therefore the cutting tools used have been explained in considerable detail.

Fourth: It is well worth while to look up or reason out correct answers to questions concerning a subject in which one is interested; it not only adds that bit of information to the store of facts one has but makes for progress. Several hundred questions appear in the book as an incentive.

Fifth: Information concerning operations and methods, or suggestions concerning typical setups may be expected from a text, and brief instructions regarding the job at hand may be obtained from the foreman or the instructor. However, the student must understand that if he hopes to succeed, he must use his own reasoning powers and develop his resourcefulness. Hence, principles have been discussed and unnecessary details omitted.

Only occasionally has a concrete example of a specific operation been given, because jobs vary daily in every shop. Rather the aim has been to give the reason underlying the particular construction, the principles which determine the right setup, the "why" of the proper cutting tool for the given purpose, and as far as possible in so brief a text, a survey of established usages and methods of operating the machine in question.

It is hoped that these pages will prove helpful to the young man beginning his work on the various machines; that the text is clear, comprehensive, and interesting enough for the reader to enjoy studying it. Also, that the descriptions and illustrations, the suggestions and the questions, will stimulate the student to seek further information contained in numerous treatises on machine tools.

H. D. B.

JERSEY CITY, N. J.,
May, 1922.

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THE DRILL PRESS

CHAPTER I

DRILL-PRESS CONSTRUCTION

1. Introduction.—In every machine shop many sizes and sorts of holes must be made in metal parts. Some of these holes must be very smooth and straight, of an exact size and accurately placed. Others are not so particular as to size or location. In any case, to be produced *efficiently* all holes must be made with the proper tools for the purpose, and in machines properly set up and operated. A knowledge of drilling machines and the tools used is one of the most important factors in machine-shop practice. A machinist must have this knowledge.

Study the mechanical features of speed changes, feed changes, adjustments of spindle and worktable. Get acquainted as soon as possible with the names and uses and the particular characteristics of the cutting tools and their holding devices. Learn to tell by the "feel," by the sound, by the chip, whether or not a drill or other cutting tool is working as it should. Have the setup look as if a mechanic did the job—neat and trim, with the clamps or stop correctly placed. Almost anybody can drill a hole, but the machinist's job is to know the why of the construction of the machine, the characteristics of the tools used, the successive steps of the operations involved, and how to lay out the work, set up the job, and finish the holes to specifications.

Although other cutting tools are often used, the twist drill is most important. Whether the drill is large or small, carbon or high-speed steel, held in a chuck or otherwise, used with a jig or not, the principles of its operation are the same.

And whatever size or design of drilling machine is used, with any method of speed and feed changes, the fact remains that sharpening the drill, holding the work, setting the speed and feed, and drilling the hole, call for machine-shop training—study and practice. It is not an involved training, but it does call for understanding and judgment.

2. The Drilling Machine.—The common mechanical feature of all drilling machines consists of a spindle (which carries the drill or other cutting tool) revolving in a fixed relative position in a sleeve which does not revolve but which may slide in its bearing in a direction parallel to its axis. When the sleeve carrying the spindle with the cutting tool is caused to move in the advance direction (usually downward), the cutting tool approaches or is fed into the work, and when moved in the opposite direction, the cutting tool is withdrawn from the work. That is, the spindle holds the drill, and the non-revolving sleeve *carries* the revolving spindle and drill. Feed-

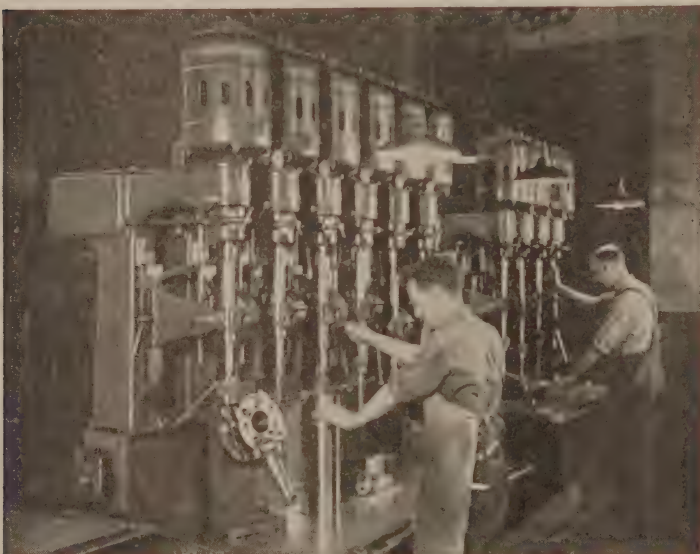

Fig. 1.—A battery of drills in a manufacturing department. (*Courtesy of The Taft-Pierce Manufacturing Company.*)

ing pressure is applied to the sleeve by hand or power and causes the revolving drill to cut its way into the work a few thousandths of an inch each revolution. (The way the sleeve is moved up or down by the feed pinion and rack is shown in

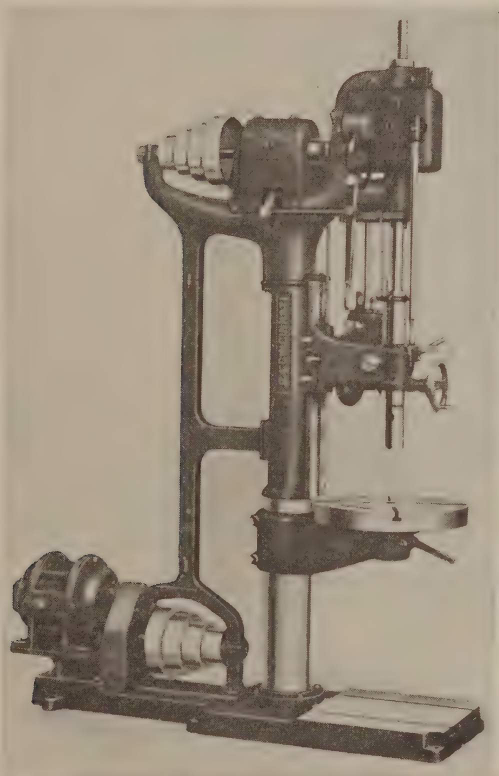

FIG. 2.—Standard upright drilling machine with spindle-reversing mechanism. (*Courtesy of The Cincinnati-Bickford Tool Company.*)

Fig. 10.) In most drilling machines the spindle is vertical and the work is supported on a horizontal table.

Like all other machine tools, drilling machines are of many kinds, with a wide range of sizes. The mechanical principles of speed and feed changes differ in no particular respect from those found, for example, in lathe construction. The machine

may be driven by a belt or by motor direct. The various speeds and feeds may be obtained through cone pulleys or gears. All except the smaller sizes (sensitive drills) have power feeds.

Several manufacturers now feature drilling machines having hydraulic feeds. This is an especially important development in machines used in manufacturing large quantities of duplicate parts.

3. The Standard Drill Press.—This machine (Fig. 2), sometimes called upright drill press or simply drill press, has six or more spindle speeds and three or more automatic feeds. Most drill presses have circular columns, although some have square box-section construction (refer to Fig. 14). The head, which carries the sleeve, spindle, and feed gears, is in many models bolted to the frame, and to accommodate different heights of work the worktable is vertically adjustable or may be swung entirely out of the way and the work seated on the base. On other types, especially those having gear feed instead of belt feed, the head also has considerable vertical adjustment on a finished flat surface on the front of the column, as in Fig. 2. This gives a wider range for heights of work. The head is balanced by a counterweight within the column.

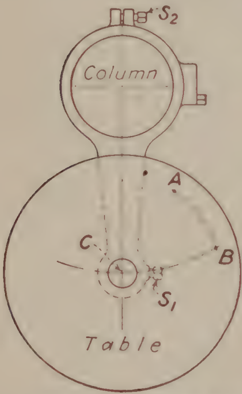

FIG. 3.—To bring any point A under the drill, loosen S_1 and S_2, pivot the table from A to B on C as a center, and then swing the arm and table on the column until A is under the center of the drill.

The standard drill press may have either a rectangular or a round worktable. In the machines with the round column (Fig. 2) the worktable is supported on an arm which is girdled on the finished lower section of the column. There are three ways in which this worktable may be adjusted for position: (1) The supporting arm (and table) may be raised or lowered; this provides for different heights of work. (2) The supporting arm may be swung to substantially 90 deg. either side of center, and (3) the table itself, being pivoted at its center, may be

swiveled[1] through 360 deg. The adjustments (2) and (3) in combination provide for locating, directly under the cutting tool, any given spot on the work when the work is clamped or is for some other reason impracticable to move about on the table (see Fig. 3).

A *compound table*, rectangular in shape, having both longitudinal and lateral movements as desired, is shown in Fig. 4. Some of these tables are merely adjustable; others are made for extreme accuracy. Note in Fig. 4 the two dials for reading

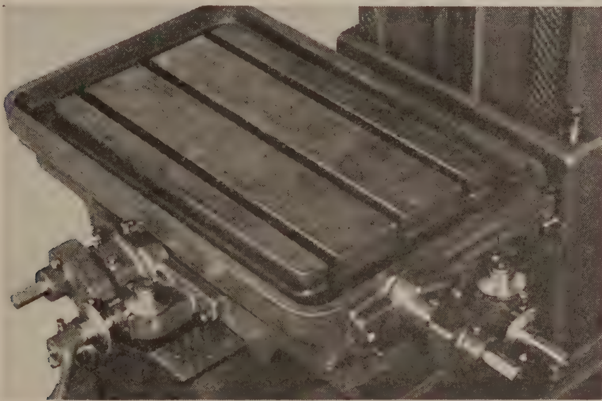

FIG. 4.—Compound table for drill press. This has very accurate adjusting screws, with dials reading ten-thousandths of an inch. (*Courtesy of The Cincinnati-Bickford Tool Company.*)

the location, or the movement, of each slide; one dial reads thousandths and the other in ten-thousandths of an inch.

Upright drill presses are classified as to size by the diameter of the largest piece that can be centrally drilled, that is, by approximately the diameter of the table, as 15 in., 21 in., up to 42 in.

4. The Sensitive Drill Press.—This machine (Fig. 5) is used for drilling small holes with hand (sensitive) feed. They are made in various sizes and may have from one to eight spindles (see Fig. 7 for similar gang drill). Some of the

[1] *Swivel.*—In machine tools, a construction which permits a part to turn or swing on a column or pivot through more or less of an arc with (usually) provision for clamping in the desired position.

smaller sizes are set on the bench and are called bench drills. The head and worktable have vertical adjustments; no other adjustment of the table is needed.

5. The Radial Drill.—This machine (Fig. 6) is especially useful when drilling several holes in the larger and heavier pieces. It has taken the place, to a considerable extent, of the larger upright drills because it has a much wider range, is more convenient to handle and greater production is possible. The spindle head is mounted on a radial arm which is girdled on the column. The head is adjustable along the arm, and the arm may be swung in a horizontal plane to any desired position within limits. These features permit of quickly locating the cutting tool over any point within a considerable area. Further, the arm may be raised or lowered to accommodate a wide range in heights of work. Various kinds and sizes of tables, plain and adjustable, are made which, when in use, are bolted to the base. Radial drills are classified as to size by the length of the arm.

FIG. 5.—Single-spindle sensitive drilling machine. (*Courtesy of Henry & Wright Manufacturing Company.*)

6. The Gang Drill.—This is a collection in one machine (Fig. 7) of the essential speed and feed units of from two to eight single drill presses mounted on one base and provided usually with one vertically adjustable worktable extending under all the spindles. The speed and feed units, also the vertical adjustments of the heads, are individual and independent. One or more of the spindles may be provided with the reversing gears or "tapping attachment." This type of machine is a manufacturing machine and is primarily intended

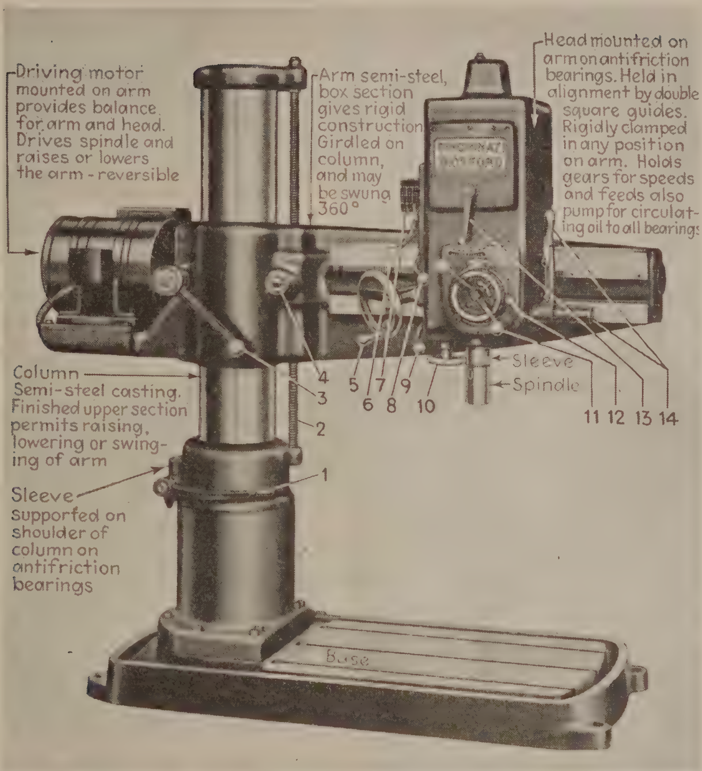

FIG. 6.—High-speed super-service all-geared radial drill. (*Courtesy of The Cincinnati-Bickford Tool Company.*)

1. Sleeve-clamping lever.
2. Elevating screw.
3. Arm-control lever. Power from the driving motor is transmitted through a multiple-disk clutch to raise or lower the arm on the column. Lever controls this, also the clamping and unclamping of the arm.
4. Hand elevating shaft.
5. Handwheel for head traverse on arm.
6. Speed-control handle.
7. Speed chart.
8. Lever for clamping head to arm.
9. Spindle-control lever, operates built-in push buttons to control forward and reverse rotation, and stopping of spindle.
10. Handwheel for fine hand feed.
11. Feed clutch, also handle for rapid advance or return of spindle.
12. Dial-clamping lever for automatic-feed trip.
13. Feed-control lever and chart.
14. Hand-feed lever.

for work held in a jig which may be easily slid from spindle to spindle for successive operations. A very wide range of sizes and kinds of gang drills are manufactured, from the smallest sensitive drills to the heavy-duty power-feed machines. Gang drills designed and fitted especially for the production of a given part are not uncommon.

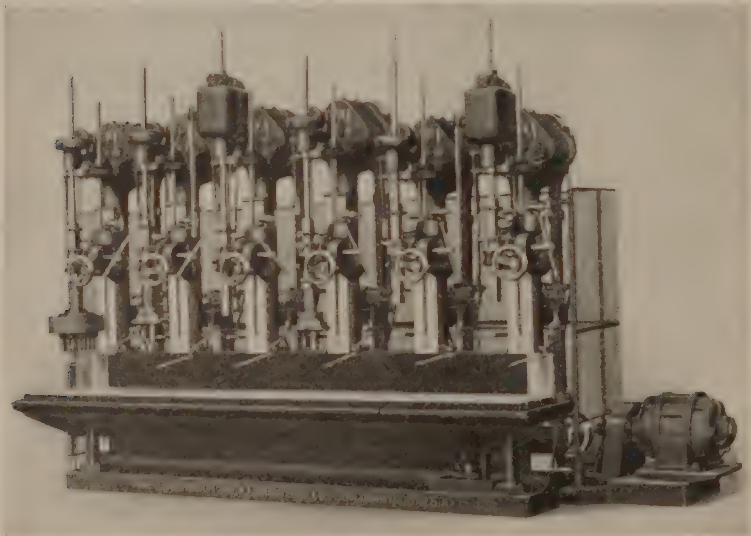

FIG. 7.—Gang drill with motor drive and cutting-lubricant system. Has counter-balanced head construction, each head with independent speeds and feeds. On the machine illustrated, two spindles have tapping attachments, and one, at the left, is shown with a multiple-spindle head. (*Courtesy of The Cincinnati-Bickford Tool Company.*)

7. The Adjustable Multiple-spindle Drill.—This type of machine (Fig. 8) contains usually 16 to 20 spindles operated simultaneously from one driving shaft. The spindles are supported in brackets which are adjustable horizontally with a considerable range, and the locating of drills in the relative positions desired can be done easily and quickly. The spindles are also adjustable vertically, which feature takes care of uneven wear of drills, etc. In most machines of this type the drill head is stationary, and the feed is accomplished by moving the worktable, either automatically or by hand or foot power.

The worktable unit is counterbalanced by a permanent weight within the column, and the weight of the work and the jig is counterbalanced by means of auxiliary weights similar to those used in weighing machines.

When manufacturing large numbers of duplicate pieces containing two or more holes of substantially the same size, this type of machine is a time saver. A drill jig must be used to give the greatest accuracy and efficiency (see Fig. 38).

Several types of auxiliary multiple-spindle drilling heads are made that have proved very efficient in rapid drilling of small holes in duplicate pieces. These attachments may be used in almost any kind of drilling machine of sufficient size.

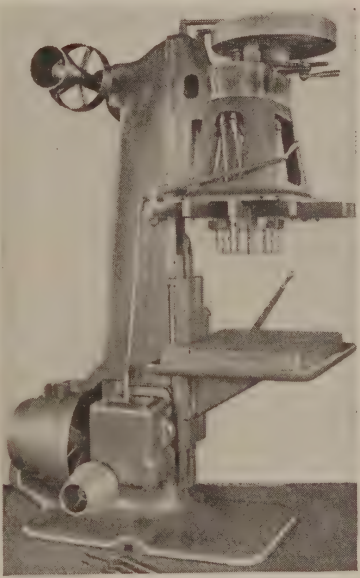

FIG. 8.—Multiple-spindle drilling machine. (*Courtesy of Pratt & Whitney Company.*)

8. Parts of the Drill Press.—In Fig. 9 a standard drill press is illustrated, and the parts are numbered and named. Brief descriptions of the mechanisms are given in the text. These part names and descriptions apply practically to any drill press and similar constructions are found in all drilling machines. Do not be satisfied merely to operate the machine —real satisfaction comes in knowing the construction and capabilities of the machine.

9. Drill-press Drive.—Power is transmitted from the line shaft to the "loose" pulley (1) in Fig. 9. By moving the belt shifter (3) the lower cone pulley, keyed to the same shaft as the "tight" pulley, is caused to rotate. The lower and upper cone pulleys (4) and (5) are connected by belt, and having the clutch (8) "in" [lever (10) pulled toward operator] and

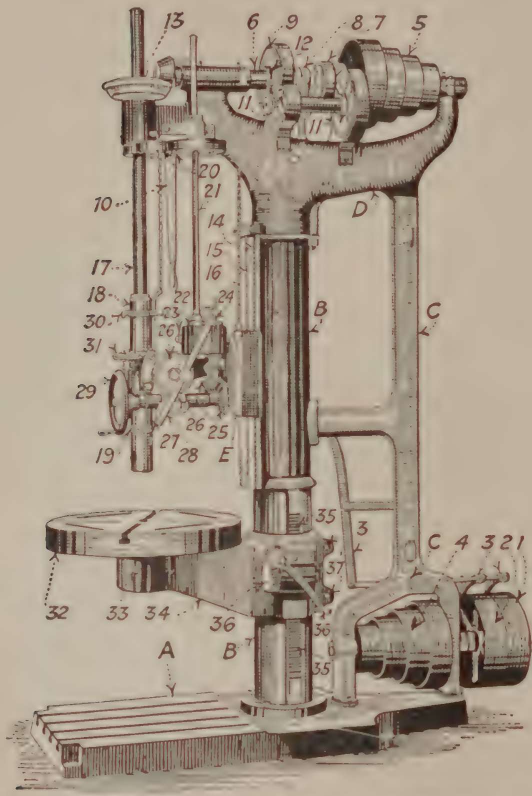

FIG. 9.—Drill press. (*Courtesy of The Cincinnati-Bickford Company.*)

PARTS OF THE STANDARD DRILL PRESS

A. *Base.*
B. *Column.*
C. *Driving pulley support and brace for yoke.*
D. *Yoke.*
E. *Head.*

Driving Mechanism.

1. *Loose pulley.*
2. *Tight pulley.*
3. *Belt shifter.*
4. *Lower* (driving) *cone pulley.*
5. *Upper* (driven) *cone pulley.*
6. *Spindle-driving shaft.* In machines which are not equipped with back gears the cone pulley (5) is fastened directly to this shaft. In machines with back gears the cone pulley, together with the friction-clutch cup (7), runs freely on the shaft, but may be connected directly (for faster series of speeds) by shifting the clutch (8) to expand the friction ring in the friction-clutch cup, or indirectly (for the slower series of speeds) by shifting the clutch to opposite position, expanding friction ring in face gear (9) thus driving through back gears (11) (detail Fig. 13).
7. *Friction-clutch cup.*
8. *Friction clutch.* This sliding member of the clutch carries a long key or wedge for expanding the friction ring in (7) or (9). This key slides in a groove cut in the hub of the friction-clutch bush which is keyed to the spindle-driving shaft.
9. *Face gear.*
10. *Friction-clutch operating lever* (pulled toward the operator for direct speeds, pushed away for back-gear speeds, middle position neutral).
11. *Back gears.*
12. *Back-gear handle* (operates back-gear eccentric shaft to engage or disengage back gears).

the back gears (11) "out" as many direct speeds of the spindle-driving shaft are obtainable as there are steps on the cone pulley. (In the drill press illustrated in Fig. 9, there are four speeds.) By changing the position of the clutch [lever (10) pushed away from operator] and putting back gears "in," as many indirect or back-gear speeds of the driving shaft are obtainable as there are steps on the cone pulley. Since motion is transmitted from the spindle-driving shaft through the bevel gears (13) to the spindle (which is feathered in the hub of the lower gear) there are, therefore, eight spindle speeds in the drill press illustrated. These speeds are practically in geometrical progression from 15 to 450 r.p.m.

10. The Feeding Mechanism.—The power-feed mechanism, whether belt-driven or gear-driven, is for the purpose of causing the cutting tool to feed into the work a given amount, from 0.004 in. per revolution for the smaller sizes of drills (about $\frac{1}{4}$ in.) to 0.040 in. per revolution for the larger machine reamers.

The spindle (17) in Fig. 9 revolves in, and is carried up or down by, the sleeve (18) which may slide vertically through its bearing in the head, the vertical movement being accomplished through a pinion engaging a rack (27) fastened to the sleeve. The pinion shaft may be moved by hand or power.

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13. *Spindle-driving gears* (bevel) for transmitting motion from the driving shaft (6) to the spindle (17).

Head, and Feeding Mechanism.

14. *Finished face of column* on which the head may be adjusted vertically.

15. *Rack* for adjusting head vertically (rack pinion is located inside of head casting. Pinion-operating handle and head-clamping screws are on left-hand side of head).

16. *Head counterweight chain;* counterweight within the column.

17. *Spindle.*

18. *Sleeve.*

19. *Ball thrust-bearing* between spindle and sleeve.

20. *Feed gears* (for transmitting motion from spindle to feed shaft).

21. *Feed shaft.*

22. *Feedbox* (for detail see Fig. 12).

23. *Feed-change handle* (for clutch).

24. *Feed-change handle* (for spring key)

25. *Feed gears* (bevel).

26. *Feed worm* and *wormwheel. Feed-rack pinion* (not shown) is on same shaft as wormwheel and meshes with feed rack (27) (detail Fig. 10).

27. *Feed rack* (attached to sleeve).

28. *Handle* for quick advance or return of spindle.

29. *Wheel* for hand feed.

30. *Feed stop* (adjustable).

31. *Feed-trip trigger* (tripped by feed stop (30) or by hand). Releases lever which holds worm in mesh with wormwheel, allowing it to drop out of mesh, thus stopping automatic feed.

Worktable and Supporting Arm.

32. *Worktable* (may be swiveled on its center through 360 deg.).

33. *Table-clamping screw.*

34. *Table arm,* adjustable vertically on finished portion of column, also girdled and may be swung horizontally through considerably more than 180 deg.

35. *Table-elevating rack.*

36. *Wormwheel, worm,* and *handle* for moving table vertically. [Rack pinion (not shown) on same shaft as wormwheel.]

37. *Table-arm clamping screws.*

The handle (28) on the pinion shaft is provided for sensitive hand feed, and also for quickly advancing or returning the spindle [first tripping feed-trip trigger (31) to disengage worm from wormwheel]. The regular hand feed is accomplished by means of the handwheel (29) through the worm and wormwheel (26) [first placing feed-change handle (23) in neutral

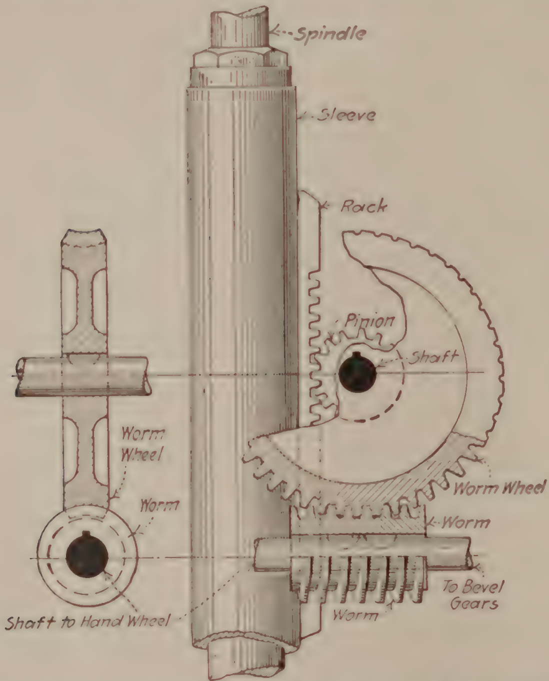


FIG. 10.—Shows spindle and sleeve, also worm, wormwheel, pinion, and rack for moving the sleeve and spindle to feed the cutting tool.

position]. The detail of the worm and wormwheel is shown in Fig. 10.

The automatic feed is obtained from the revolving spindle through the gears (20) to feed shaft (21) through gearbox (22) through bevel gears (25) through worm and wormwheel (26) to pinion and rack. The automatic feed stop (30) may be adjusted to disengage the feed at any predetermined depth. (Figure 11 is included for clearness.)

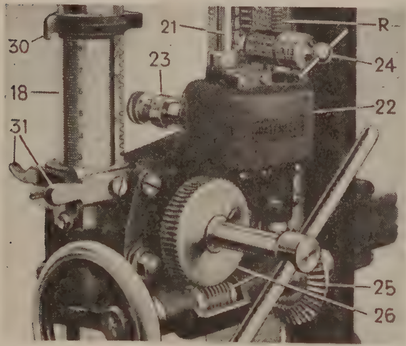


FIG. 11.—Feedbox, bevel gears, worm, and wormwheel (with guards removed), numbered the same as Fig. 9.

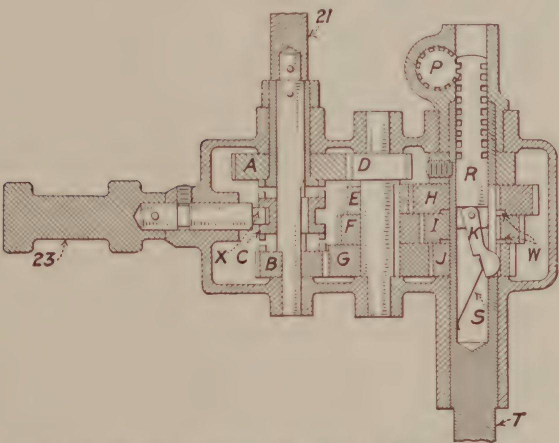


FIG. 12.—Vertical section through feedbox of Cincinnati-Bickford upright drill (Fig. 11). One series of feeds (the slower series) is obtained by engaging the clutch *C* with the driving gear *B* and engaging the sliding spring key *K* in the different driven gears. For example, the slowest feed is obtained by engaging the clutch *C* in gear *B* and the spring key in gear *H*. Motion is transmitted through a compound gear train, from smaller gear *B* to the larger gear *G* and from the smaller gear *E* to the larger gear *H*, causing the driven shaft *T* to revolve much slower than the feed shaft (21).

The faster series of three feeds is obtained by engaging the clutch *C* with the driving gear *A* and engaging the key in the different driven gears. For example, the fastest feed is obtained by engaging the clutch *C* in gear *A* and the spring key in gear *J*. Motion is transmitted through a compound gear train, from the larger gear *A* to the smaller gear *D* and from the larger gear *G* to the smaller gear *J*. The gearbox is designed to give six positive feeds, in fractions of an inch per revolution of the spindle from .006 in. slowest to .039 in. fastest, in geometrical progression.

Six feeds are available through the quick-change gears enclosed in the gearbox (22) by changing the position of the handles (23) and (24). This mechanism is described in the following paragraph.

11. The Quick-change Gearbox.—The diagram of the mechanism within the gearbox is shown in Fig. 12. The positive clutch *C* is feathered on the feed shaft (21) and is operated by the handle (23), through the eccentric at *X*, to engage the clutch teeth in the hub of either of the driving gears *A* or *B* which otherwise revolve freely on the shaft. The cone of gears *D*, *E*, *F* and *G* are keyed to the intermediate shaft and revolve with it, the gears *E*, *F*, and *G* engaging, respectively, the driven gears *H*, *I*, and *J* which revolve freely on the driven shaft. The key *K* is hinged on a pin in a slot in the lower end of the rod *R*. This rod may slide freely in the hollow driven shaft *T* and is operated by a handle (24, Fig. 9) through the pinion *P* which engages the teeth similar to rack teeth formed by cutting grooves around the upper end of the rod. The force of the spring *S* serves to push the spring key or "dive key" *K* through a slot in the hollow shaft and into the keyway of a driven gear, *H* or *I* or *J* as desired. Hardened washers *W* are placed between the gears to prevent the key from engaging two gears at the same time.

12. Sliding Gears for Feeds.—The sliding-gear principle is much used for feed gears, especially in the high-duty machines. The gears are of special steel, heat-treated, and mounted on multiple-spline shafts which run in antifriction bearings. Figure 16 illustrates sliding gears for nine feeds.

13. Reversing Mechanism or "Tapping Attachment."—Most of the upright and radial drills are now provided, if so desired, with a spindle-reversing mechanism, consisting of a clutch and suitable gears, which is known as the tapping attachment. Figure 13 illustrates the tapping attachment provided, at the option of the purchaser, as an integral part of the drill press shown in Fig. 9. The larger bevel gears G_1 and G_2 revolve freely in their respective bearings in opposite directions. The friction-clutch member *C* is feathered on the

spindle and revolves when engaged with G_1 to give the regular rotation to the spindle, and when engaged with G_2 to give the reverse. When the clutch is in midway (neutral) position, the spindle does not turn.

The friction-clutch drive permits of starting or stopping the spindle while the machine is running at any speed, and this is equally true when the intermediate gear *I* is raised out of mesh (by handle *H*) and the reversing mechanism is not being

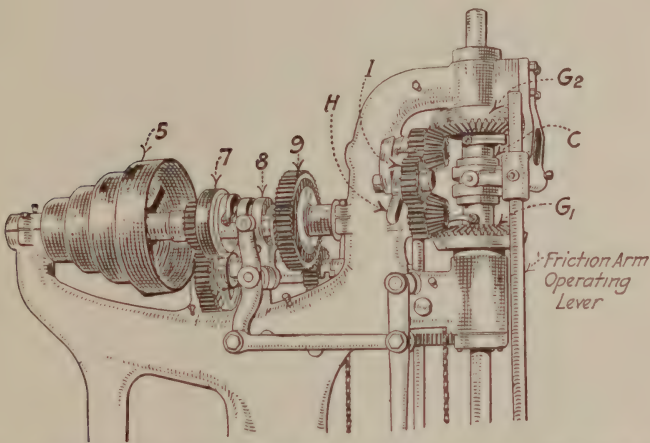


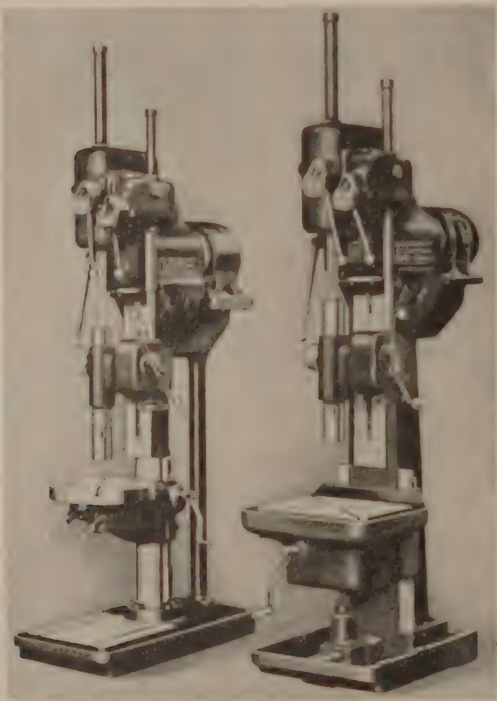
FIG. 13.—Spindle-driving gears and reversing gears or "tapping attachment," shown with gear guards removed. By means of the friction clutch the direct and indirect (back gear) speed mechanisms and the reverse gears work may be drilled at fast speed, tapped at slow speed, and the tap reversed and withdrawn at fast speed. (See also descriptions of Nos. 5-6-7-8 and 9, Fig. 9.) (*Courtesy of The Cincinnati-Bickford Tool Company.*)

used. This feature alone, as a time saver, is worth the added cost of the attachment.

14. Superservice Drill Presses.—In Fig. 14 two modern upright drill presses are shown, one with round and the other with box column. These machines have direct motor drive, with 12 spindle-speed changes and 9 feed changes through sliding gears. They are included here as examples of modern design, as expressed in simplicity, convenience in operation, appearance, and efficiency.

All speed changes are controlled by a single lever, likewise the feed changes, and both levers are provided with direct-reading index plates.

Referring to Fig. 15 the part A comprises a spur gear (1) and an internal gear C. It is free to turn (not keyed), but



(a) (b)

FIG. 14.—All-geared super-service upright drilling machines: (a) round column; (b) box column. (*Courtesy of The Cincinnati-Bickford Tool Company.*)

when the gear cluster B, keyed to the driving shaft S, is lowered to have the gear (3) engage the internal gear C (in jaw clutch fashion), the gear (1) will revolve with the shaft S.

The diagram shows the gear (3) in a neutral position; move the gear cluster B a little higher and (3) will engage (4); move it higher again and (5) will engage (6); higher still and (7) will engage (8).

Similar to part *A* is the part *D* which comprises the spur gear (10) and the internal gear (11). The part *D* is free except when (11) and (12) are engaged, at which time it transmits its motion to the cluster *E* which is keyed to the spindle. In the

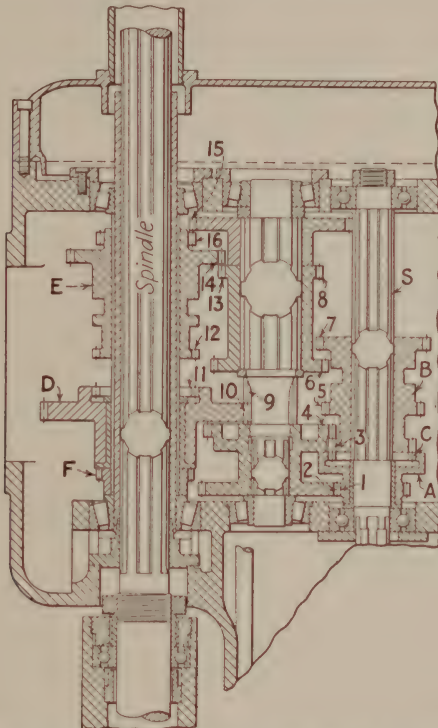


Fig. 15.—Speed-change gears in Cincinnati-Bickford upright drill (Fig. 14). Gear runs and corresponding spindle speeds in r.p.m.

1-2-9-10-11-12	60	1-2-13-14	180	1-2-15-16	460
3-4-9-10-11-12	80	3-4-13-14	230	3-4-15-16	590
5-6-9-10-11-12	105	5-6-13-14	310	5-6-15-16	800
7-8-9-10-11-12	135	7-8-13-14	390	7-8-15-16	1,000

other positions of *E*, motion is transmitted to it and the spindle through gear (14) engaging gear (13), or (16) engaging (15).

The gear *F* meshes directly with the gear *G* in the feedbox (Fig. 16) and drives the feed gearing to give any one of the nine speeds of the feed shaft (21, Fig. 9). The feed rod is

connected through bevel gears, worm and wormwheel, pinion and rack to give the drill press spindle feed similarly as shown in Fig. 10.

It is profitable machine-shop training to study the gear runs for the different speeds and feeds, for example, those illustrated in Figs. 15 and 16. Sliding gears are now used in almost all

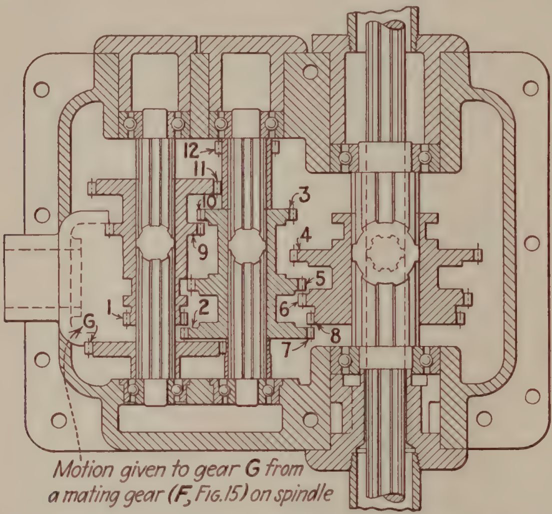


Fig. 16.—Feed-change gears in Cincinnati-Bickford upright drill (Fig. 14). Gear runs and feeds in thousandths of an inch per revolution of spindle.

1-2-3-4	0.005 in.	9-10-3-4	0.011 in.	11-12-3-4	0.025 in.
1-2-5-6	0.007 in.	9-10-5-6	0.015 in.	11-12-5-6	0.034 in.
1-2-7-8	0.009 in.	9-10-7-8	0.020 in.	11-12-7-8	0.043 in.

lathes, drilling machines, milling machines, etc. They vary in design but are alike in principle and operation.

A feature of these machines (Fig. 14) is the use of a reversing motor instead of the tapping attachment. The lever at the left of the head operates push buttons for starting or stopping the forward or reverse rotation of the spindle. A constant-speed motor suitable for 20 reversals per minute is used in connection with a magnetic reversing starter.

The spindle and sleeve are of chrome-nickel steel. The rack teeth are cast integral with the sleeve. The diagrams of the speed gears (Fig. 15) and of the feed gears (Fig. 16) serve to

illustrate units of the most advanced design and construction. They show the compact sturdy arrangement of the clusters of sliding gears, multiple-spline shafts, antifriction bearings, etc., that make for high-duty value in modern machine tools.[1]

Questions on Drill-press Construction

1. Clean the taper hole in the drill-press spindle. Why is it especially dangerous to clean a taper hole in a revolving spindle? How do you clean this hole? Why must it be clean and dry?

2. Clean the taper shank of, say, a 1-in. diameter-drill, be sure it is free from nicks and put it in the spindle, arranging the tang of the drill to enter the slot in the spindle. Place a suitable block of wood on the table, and using the handle for quick advance of spindle bring the point of the drill sharply against the block three or four times. How does this serve to drive the drill home?

3. Clean the finished portion of the column on which the table arm is supported, loosen the binding bolts, and lower the table. Raise the spindle head to its highest position. What is the maximum height of the work that may be drilled on the table?

4. Swing the table to one side. How much higher work may be held on the floor plate than can be held on the worktable?

5. How is the table raised or lowered? How is it swung to the right or left on the column? How is it turned on its own axis?

6. Why, in some drilling machines, is provision made for raising or lowering the spindle head on the front of the column?

7. What is the maximum amount of the adjustment of the spindle head?

8. How is the weight of the head counterbalanced?

9. In operation, the drill-press spindle revolves in the spindle sleeve. Does the sleeve revolve?

10. How does the sleeve move in its bearing? What does it carry with it?

11. How is the spindle supported at its upper end? How is it made to revolve? Why is a long keyway or "spline" cut in the spindle?

12. How is the drill press started and stopped? What do you mean by a loose pulley? A tight pulley? How is a loose pulley oiled?

13. How many direct spindle speeds has this drill press? How are they obtained? Has it any back gears?

14. How many spindle speeds has this drill press?

15. When are the back gears used? Why?

16. How are the back gears engaged?

[1] For description of sliding gears, multiple-spline shafts, antifriction bearings, etc., refer to the index in Part I of this text.

17. Is it safe to engage the back gears when the machine is running? Give reason.

18. What is the use of the rack fastened to the spindle sleeve? What engages it?

19. How is the spindle caused to move in a downward direction by hand? What is this called?

20. How many methods of feeding by hand are provided in this machine? Which is the most sensitive? Why? Which requires the least effort? Why?

21. Examine the mechanism that transmits motion from the spindle-driving shaft to the feed-rack pinion. How do you change the speed of the feed rod without changing the spindle speed? How many changes may be made? How many power feeds has this drill press?

22. How is the power feed engaged?

23. How do the worm and wormwheel operate to give a slow motion to the feed-rack pinion?

24. How is the power feed released? Has it an automatic release?

25. How is the automatic release set for a required depth?

26. The amount of feed is a certain number of thousandths of an inch per revolution of the spindle. How many thousandths per inch is the maximum feed that can be obtained on this drill press? What is the minimum feed?

27. What kind of a hole is in the end of the spindle? Why?

28. What is a sensitive drill press? Why is it so named?

29. What type of drilling machine is usually called simply "drill press?" Why?

30. What is a radial drill?

31. What is the advantage of a radial drill?

32. What is the value of a multiple-spindle drill?

33. What mechanical feature is common in all drilling machines?

34. How are drilling machines classified as to size?

35. What is the difference between an eight-spindle sensitive drill and a multiple drill?

36. Define: sliding gears; multiple-spline shaft; gear cluster.

CHAPTER II

DRILLS AND DRILLING

15. Drilling-machine Operations (Fig. 17).—*Drilling* is the operation of producing a circular hole by removing solid metal. The cutting tool used is called a drill.

Reaming is the operation of sizing and finishing a hole by means of a cutting tool (reamer) having several cutting edges.

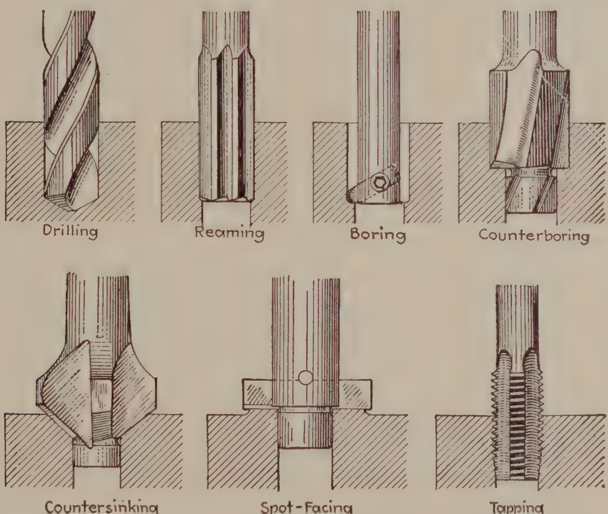


FIG. 17.—Illustrates drilling-machine operations.

Reaming serves to make the hole smoother, straighter, and more accurate.

Boring is the operation of enlarging a hole by means of an adjustable cutting tool with one cutting edge.

Counterboring is the operation of enlarging the end of a hole cylindrically, as for a recess for a fillister-head screw.

Countersinking is the operation of making a cone-shaped enlargement of the end of a hole, as for a recess for a flathead screw.

Spot facing is the operation of smoothing and squaring the surface around the end of a hole, as for the seat for a nut or the head of a cap screw.

Tapping is the operation of forming internal screw threads by means of a master tool called a tap. To withdraw the tap by power in a drill press requires either a reversible motor or a reversing attachment or "tapping attachment."

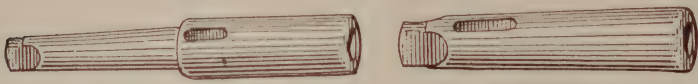


FIG. 18.—Drill-press *socket* and *sleeve*. Cutting tools with taper shanks that are too small to fit the taper hole in the spindle of the machine are held in a smaller taper hole in a socket the shank of which fits the spindle hole. If the socket makes too long an extension a "sleeve" may be used. Sockets and sleeves are made in all necessary sizes, No. 1 to No. 2; No. 1 to No. 3; No. 3 to No. 4 etc., the first number denoting the size of the taper hole and the second number the size of the taper shank. If a suitable socket or sleeve is not at hand, a combination of socket and sleeve or of two sockets or two sleeves may be used.

In this chapter information may be found concerning drills, methods of holding the work, and the operations incident to drilling. If the student gathers an understanding of drills and drilling, he may apply the knowledge to other drill-press operations, brief discussions of which are in the next chapter.

16. How the Cutting Tools Are Held.—The revolving spindle of the drill press carries the cutting tool. Some tools may be held directly in the spindle hole, others must be held in a taper socket, or drill chuck, or other device, the shank of which fits the taper hole in the spindle.

The cutting tools used for any of the drilling-machine operations (except tapping) may be made either with straight shanks or taper shanks (Morse standard). It is usually considered best to have the smaller sizes (for example, drills or reamers under ½ in.) provided with straight shanks because they can be conveniently and firmly held in a chuck

(Figs. 20 and 21), and the extra cost of the taper shank on these sizes is unnecessary. In the larger sizes the difference in cost between straight and taper shanks is not as great, and it is nearly always more convenient to hold them by means of the taper shank.

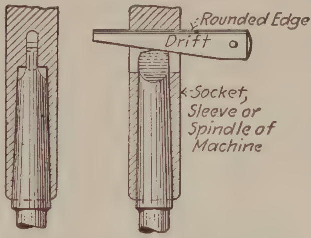


FIG. 19.—Illustrates how the taper shank with tang is held in taper hole, and also the use of the drift to remove the taper shank from the socket, sleeve, or spindle as the case may be.

17. Sockets and Sleeves.—The drilling-machine spindle is provided with a Morse standard taper hole of a size in proportion to the size of the machine. Several sizes of drills, for example, have shanks which will fit the spindle,[1] others are too small, and to step the sizes, sockets or sleeves (Fig. 18) are used. A taper key or "drift" is used, as shown in Fig. 19, to remove the taper shank from the taper hole. Do not use anything but a drift for this purpose and use the rounded edge against the rounded end of the hole.

The taper shanks of drills, reamers, counterbores, etc., and also of the sockets and sleeves, have the end flatted to form a "tang" which fits in a suitable slot at the end of the taper hole in which the shank is held (see Fig. 19). The purpose of the tang is to help drive the drill since the hold of the taper alone is not sufficient. It must be understood, however, that the tang alone is not sufficient to drive the drill or other cutting tool, and consequently the taper shank and hole must be properly fitted, clean, and dry, and the shank firmly driven home or the taper will not do its share, and the result will be a twisted-off tang. Thrust the taper shank of the drill (or of the drill chuck, if a chuck is used) into the socket and the socket into the spindle. To secure the drill and drill socket,

[1] The range of sizes of drills provided with a given size of shank is usually as follows: Sizes up to $\frac{9}{16}$-in. diameter, No. 1 Morse taper; sizes $\frac{37}{64}$ to $\frac{29}{32}$ in., No. 2 Morse taper; sizes $\frac{59}{64}$ to $1\frac{1}{4}$ in., No. 3 Morse taper; sizes $1\frac{17}{64}$ to 2 in., No. 4 Morse taper; sizes $2\frac{1}{64}$ to 3 in., No. 5 Morse taper; sizes $3\frac{1}{16}$ to 4 in., No. 6 Morse taper.

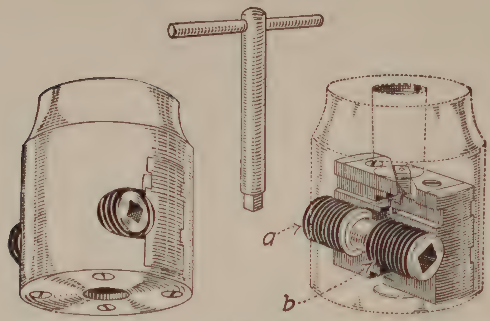


FIG. 20.—Standard type of two-jaw drill chuck. The jaws are fitted to move freely in a slot cut diametrically across the lower end of the body. The movement of the jaws is controlled by a screw arranged within the body to fit suitable threads cut in one side of each jaw. One end *a* of the screw is cut right hand while the other end *b* is cut left hand; consequently, when the screw is turned, the jaws move uniformly toward or away from each other. The clamping faces of the jaws are V-shaped lengthwise, to center the shank of the cutting tool, and notched alternately crosswise, thus fitting more or less of a distance one within the other in order to grip equally well a wide range of sizes.

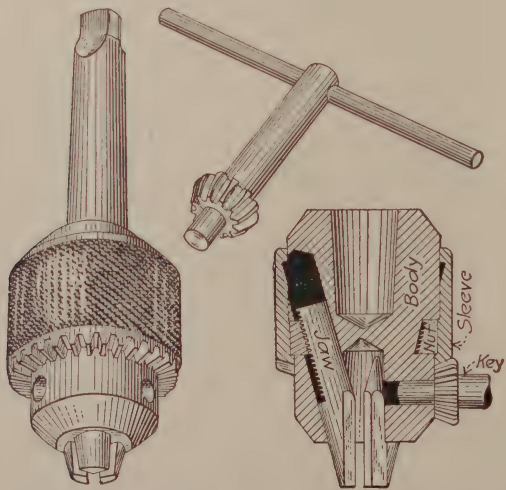


FIG. 21.—Jacob's drill chuck. One of the best and most popular chucks. The chuck may be taken apart by forcing the sleeve off over the jaw end of the chuck, when the nut, which is made in halves, may be taken out leaving the jaws free. Have the jaws partially closed before forcing off the sleeve.

put a block of wood on the table and with the feed handle bring the drill down sharply against the block to drive the drill and socket tight. If a drill chuck is used, secure it in the same manner and then grip the drill in the chuck.

18. Drill Chucks (Figs. 20 and 21).—A chuck is a gripping device with two or more adjustable jaws set radially. A drill chuck is made especially for holding *straight-shank* drills or other cutting tools in the spindle of the machine and is itself provided with a *taper shank* which fits the taper hole in the spindle. They are made in various sizes, and a series of three or four chucks will hold drills from the smallest size up to 1 in. in diameter.

Questions on Drilling-machine Accessories

1. What is a drill chuck? What kind of shank has it? Why is the shank provided with a tang?

2. If the taper shank of the drill is of a smaller size than the hole in the spindle, how is the drill held?

3. What is a drift or key used for? How is it used? What is the objection to using a drift upside down?

4. Which holds best, an oily taper or a dry taper?

5. Is the hold of the taper alone sufficient to keep the drill from turning in the socket? What two things hold the drill from turning?

6. What faults in the setting of the drill might result in the tang being twisted off?

7. Why are the smaller-size drills made with straight shanks?

8. Define drilling, reaming, boring, and spot-facing.

9. What is the difference between counterboring and countersinking?

10. If the taper shank of the chuck is too small for the spindle hole, what do you use? In any case how do you make sure the chuck is securely held in the spindle?

19. The Twist Drill.—The drills most commonly used are twist drills. The twist drill is probably the most used and most efficient cutting tool in the shop. Obtain a twist drill and referring to Fig. 22 note carefully the following features: It has two cutting edges or "lips" the upper faces of which are formed by milling two opposite grooves spirally (twisted) in a cylinder. The bottom or end faces of the cutting edges are at an angle of approximately 60 deg. with the axis. It has been

found by experience and test that the angularity of the cutting edges of about 120 deg. with each other (theoretically 118 deg.) offers the best angle for centering the drill and keeping it central without any tendency to wedge. These angular faces are "backed off" or "relieved" for clearance, and when the cutting edges become dull these faces only are ground as subsequently explained. The spiral groove (flute) is milled at an angle of about 20 to 25 deg. with the axis of the drill, thus giving the *rake*, and the cutting edge when properly ground is relieved about 10 to 12 deg. on the end, consequently the *cutting angle* is substantially 55 to 60 deg. which is correct for cutting iron

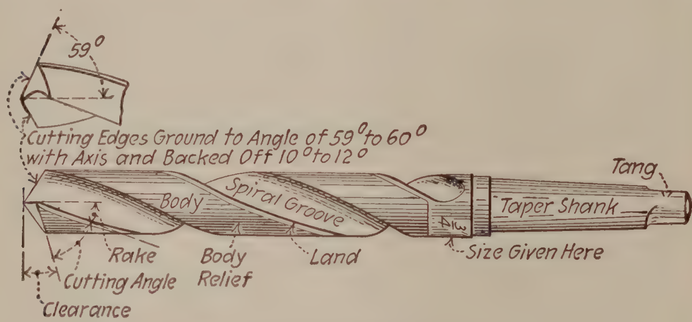


Fig. 22.—Taper-shank twist drill.

and steel. Another advantage of the spiral flute lies in the fact that the chips work out readily during the cut, making unnecessary the removal of the drill from the hole to clean it from chips even when drilling a fairly deep hole. Note that after the flutes are cut the remaining portion of the surface of the body is relieved and only a narrow *land* is left. This body clearance reduces the friction of the drill in the hole. The thinnest section of the body of the drill (between the bottoms of the flutes) is called the "web."

Twist drills are made in number sizes; No. 1 (0.228 in. diameter) to No. 80 (0.0135 in. diameter). They are made in letter sizes; *A* (0.234 in. diameter) to *Z* (0.413 in. diameter) (see Table 20). They are also made in sizes ranging by 64ths of an inch from $\frac{1}{64}$ in. to 4 in. or more, and in metric

sizes, ranging from 0.4 mm. (0.0157 in.) to 50 mm. (1.068 in.) by 0.1 mm. (about 0.004 in.) on the smaller sizes, and by 0.5 mm. on the larger sizes. The smaller drills are not marked and the size is found by the use of a drill gauge (Fig. 23).

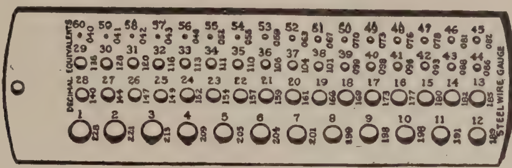


Fig. 23.—Drill gauge.

20. The Straight-fluted Drill.—For drilling brass, copper or other soft metals a drill with rake (a twist drill) has a tendency to "dig" or "grab." A straight-fluted "Farmer" drill (Fig. 24) is the best to use for soft metals, but a twist drill

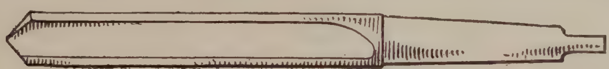


Fig. 24.—Taper-shank straight-fluted drill.

may be used if the fronts of the lips are ground as shown in Fig. 25. It is also advisable to use a drill without rake when drilling very thin stock owing to the tendency of the drill to "hook into" the work when it is breaking through. A drill ground in this manner is very effective for drilling unannealed steel and "hard spots" in cast iron when turpentine is used as a lubricant.

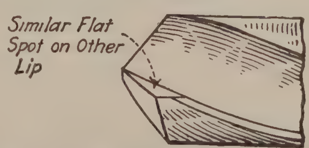


Fig. 25.—Twist drill ground for brass.

21. The Flat Drill.—Occasionally when it is required to drill a hole of a size for which a twist drill is not at hand, it is convenient to know that a flat drill (Fig. 26) that will do good work may be made easily and quickly. A piece of round tool steel of a suitable size is forged flat on one end, centered, the shank turned straight or taper as desired, and the narrow sides of the flat portion turned to the size required. If the drill is of a sufficient size to warrant the extra operation, the cutting

edges can be turned to the included angle of 120 deg. leaving a teat which may then be filed off. If greater accuracy is required, the shank and "body" may be left large enough to grind on centers after hardening and tempering. In this case

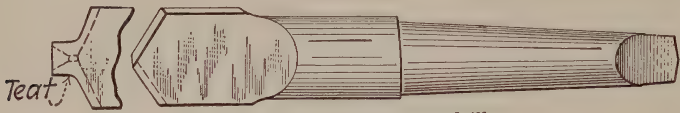


FIG. 26.—Homemade flat drill.

the teat will, of course, be left on until these surfaces are finished and will be ground off when the drill is sharpened.

22. The three-fluted drill (Fig. 27), so called because it resembles a twist drill, would perhaps more properly have been

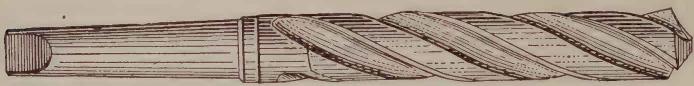


FIG. 27.—Three-fluted drill.

named a three-tooth spiral reamer since its function is enlarging cored, punched, or drilled holes. It will not drill the initial hole, but being very sturdy and having wide cutting edges, it is an efficient tool when a hole must be considerably enlarged.

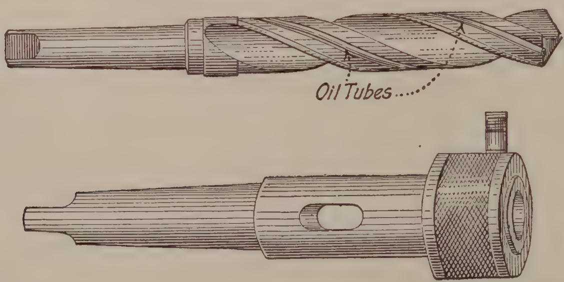


FIG. 28.—Oil-tube drill and oil-feeding socket. (*Courtesy of Cleveland Twist Drill Company.*)

23. Oil-tube Drills.—When manufacturing quantities of steel parts in which it is required to have holes $\frac{1}{2}$ in. or more in diameter drilled fairly deep it has often proved economical to use drills with oil tubes (or holes) running lengthwise spirally

through the body to carry the oil directly to the cutting lips. Such a drill with the necessary oil-feeding socket is illustrated in Fig. 28. The oil is carried from the reservoir (any suitable can or pail set fairly high to give sufficient pressure and provided with a stopcock will do) through a pipe to the tube on the side of the collar. The collar may be held from turning with the socket by using a piece of 1/4 in. gas pipe long enough to reach the column of the machine or other suitable stop. The collar and also the body of the socket are provided with channels through which the oil is forced into the holes in the shank of the drill, which register with the channels, and thence through the tubes in the drill to the cutting edges.

SHARPENING A DRILL

24. Drill-grinding Machine (Fig. 29).—In shops where any considerable amount of drilling is done it is economical to have

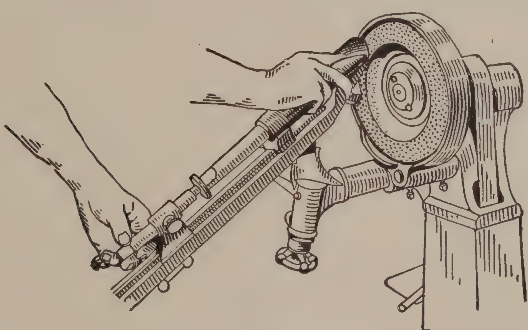


Fig. 29.—Drill grinder.

a drill-grinding machine. This machine may be quickly adjusted to support a drill of any length or diameter in a wide range of sizes and is so designed that it is a very simple matter to grind the drill properly, that is, with the lips of equal length, at the correct angle with the axis, and with the correct clearance. However, there are many times when it is advisable and even necessary to grind a drill by hand, and every *real* machinist knows how to do it correctly and quickly.

25. Principles of Sharpening a Drill.—Although high-speed drills have gained place in production work, most of the smaller

sizes (¼ in. and under) are still made of carbon steel. When using or sharpening a carbon-steel drill, extra care must be taken not to let it get hot enough to lose the temper. If the cutting edge shows blue, it indicates the temper has been lost

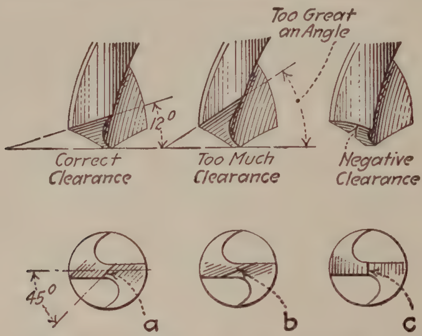


Fig. 30.—From the appearance of the "dead centers" of the drill points—the lines a, b, and c—the machinist would know if the lip clearance is correct or not, as indicated in the corresponding figures above.

in that part, and the drill must be shortened that much in order to grind the soft part away. This means not only extra work but waste of the drill. Have plenty of water and use care. If necessary to grind a high-speed drill dry, never dip it in water to cool it, as this is likely to crack the lips.

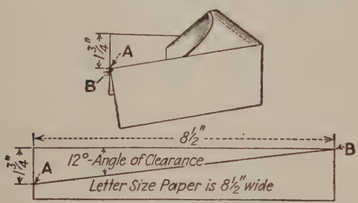


Fig. 31.—A piece of paper 8½ in. long marked off 1¾ in. and wrapped around a drill as shown will indicate 12-deg. clearance.

The idea in sharpening a drill is to have the cutting edges (1) the same length, (2) the same angle with the axis of the drill, and (3) ground to have the proper clearance. Perhaps the most difficult for the beginner to get is the clearance. Refer to Fig. 22 and note that the drill, like every other cutting tool, has a cutting angle, a cutting edge, and *clearance.*

The clearance on a drill is about 12 deg. at the cutting edge. If correctly sharpened, the edge of the angle across the web of the drill (the "dead center" of the drill) will be about 45 deg. with the line of the cutting edges (see a, Fig. 30). The

appearance of the dead center is therefore an index to the clearance; when it is like *b*, the lips have too much clearance, and when it is like *c*, the lips have no clearance. Lip clearance is very important as it takes considerable pressure to feed the

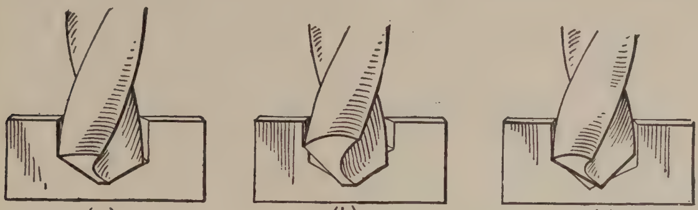


FIG. 32.—(*a*) Lips of different lengths; drill will cut oversize. (*b*) Lips with different angles with axis of drill; drill will wabble and cut oversize. (*c*) Lips with different inclinations; one lip does practically all the work which tends to crowd the drill toward the opposite side and wear off the land.

drill into the work under the best possible conditions, owing to the nature of the point, and if the lips are not properly backed off, the drill will break under feeding pressure simply because it cannot cut.

Beginners seem to have a tendency to ignore the idea of clearance and get either too much or none at all. Watch the clearance! If one has difficulty, at the start, in judging the 12-deg. angle of clearance, a piece of paper 8½ in. wide (composition paper, for example) may be used, as shown in Fig. 31.[1]

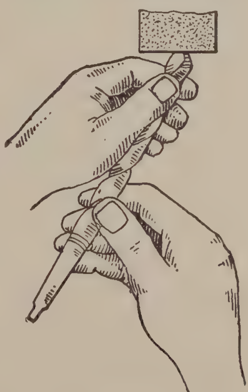


FIG. 33.

Great care must be taken to get the lips exactly the same length and both at the same angle with the axis of the drill, or the hole will be oversize. This is illustrated in Fig. 32.

Theoretically, if the edges of the drill are ground at an angle of 59 deg. with the axis, the best results will be obtained in most materials. Therefore the drill should be held at about 59 or 60 deg. with the face of the grinding wheel (see Fig. 33).

[1] C. RIDDERHOFF, in *Am. Machinist*.

For testing the angles, and the relative lengths of the cutting edges, there are several kinds of gauges, four types being made by The Morse Twist Drill and Machine Co. If no gauge for the angles is at hand, one like *b* in Fig. 34 may be easily made. The student who tries will soon learn to notice any inequality in the lengths of the lips, or in their angles with the axis of the drill, without the use of any gauge.

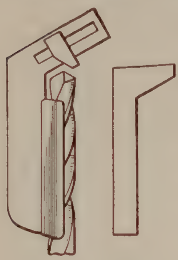

(a) (b)

Fig. 34.

In order not to waste an expensive drill, grind for practice the end of a piece of flat stock, say ⅛ by 1 in., to the shape of the cutting edges of a flat drill, as shown in Fig. 26.

26. The Operation of Sharpening a Drill.—1. Hold the drill with hands placed about as shown in Fig. 33.

2. Have the axis of the drill (or practice piece) about 60 deg. with the face of the grinding wheel. This will give the 120-deg. angle between the cutting edges.

3. Hold the edge to be sharpened parallel to the top of the tool rest, that is, in a horizontal position.

4. Hold the right hand (and the shank of the drill) a little lower than the left hand and press the drill against the grinding wheel. Holding the shank end a little lower serves to give the clearance.

5. Grind the other lip in the same manner.

6. If the right hand is too far down, too much clearance will be ground, and the end will look like *b* in Fig. 30; if not down far enough, no clearance or *negative* clearance may result, like *c* in Fig. 30.

7. Do not grind too much off one lip before grinding the other; keep them pretty much alike, and when finished, they should be of the same length and the same angle with the axis of the drill.

8. When both lips are ground correctly, then grind the "heels"—the remainder of the end of the drill—just enough to make a finished job.

9. Do not *twist* the drill when grinding it, pivot it a little (rock it) in the left hand, enough to give the clearance, and later to grind off the heel.

10. Grind in a direction *from* the edge *to* the heel, never from the heel to the edge

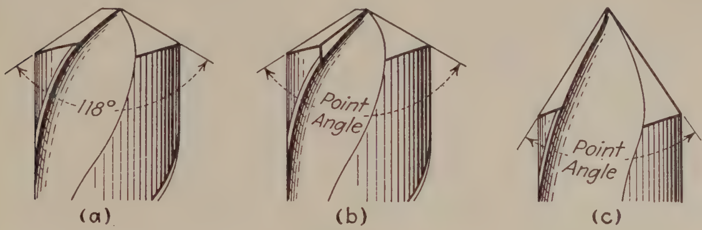


FIG. 35.

27. Drill Points for Different Materials.—The point angles of twist drills vary for different materials from 60 to 150 deg. with about 118 deg. for average work (see Fig. 35). The Morse Twist Drill and Machine Co., after many experiments with different angles of points in various grades of materials, recommend the following (refer to Fig. 35):

150 deg. for hard materials, flatted as in *b*, and with not over 10-deg. clearance.
125 deg. for heat-treated steel and drop forgings.
118 deg. for average class of work (shown in *a*).
100 deg. for copper.
90 deg. for soft cast iron.
60 deg. as in *c*, for wood, hard rubber, bakelite, and fiber.

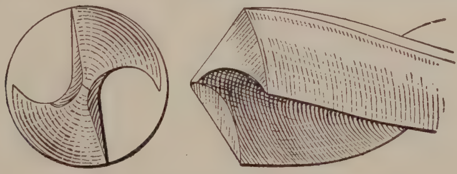


FIG. 36.—Thinning the point of a drill.

28. Thinning the Point of a Drill.—To strengthen a drill the web is made thicker toward the shank. This is not noticeable on drills under $\frac{3}{4}$ in. in diameter; but on larger sizes, as the drill is shortened, it becomes necessary to grind the

point somewhat thinner as shown in Fig. 36. Use a narrow grinding wheel and be careful to preserve the center by grinding an equal amount from each side, and not to weaken the web unnecessarily by thinning too far back.

29. Speeds and Feeds of Twist Drills.—Owing to the variations of the hardness and toughness of the materials used in machine-shop practice, no hard and fast rule can be given for the speeds and feeds of twist drills.

The correct speeds and feeds must be determined by the judgment of the operator, and the following hints will help the beginner to obtain this necessary knowledge.

When the cutting edge breaks off, the feed is too heavy or the drill has been given too much clearance (see *b*, Fig. 30).

When the drill splits, there is too much feed or the drill has not been given enough clearance. *There seems to be a tendency for the beginner to give insufficient lip clearance toward the center of the drill. The whole length of the lip must be backed off or the drill will surely break under the feeding pressure.*

The rapid dulling of the drill especially at the outer ends of the lips (the corners) is evidence of too much speed.

When a drill squeaks, it is usually an indication of a crooked hole or dullness. Never allow a drill to squeak.

The following tables of speeds and feeds are given here as having proved practical for average conditions:

Average Cutting Speeds with Drills of High-speed Steel

Stainless steel and Monel metal	50 ft. per min.
Annealed high-carbon (tool) steel	60 ft. per min.
Low-carbon (machine) steel	80 ft. per min.
Very soft steel and soft gray iron	100 ft. per min.
Brass and copper	200 ft. per min.
Aluminum	300 ft. per min.

Average cutting speeds with carbon steel are about half the above.

Average Feeds for Drills

Same feeds *per revolution* for high-speed as for carbon-steel drills.
Sensitive (hand) feed for number-size drills.
0.005 in. per revolution for ¼ in. to 0.015 in. for 1½ in. and up.

30. Calculation for R.P.M. of Drill.—To know how to get the number of revolutions per minute (r.p.m.) of the spindle to give the proper cutting speed (CS) for the given diameter of drill is very important. The method and formula are given here, the derivation of the rule and formula is explained in paragraph 198, page 241.

Method: To obtain the number of revolutions of the drill-press spindle necessary to give the proper cutting speed for the drill, proceed as follows: (1) know whether the drill is carbon-steel or high-speed steel; (2) determine what cutting speed is suitable for that kind of drill and the material it is to cut (from experience or from a table as above); (3) divide one quarter of the diameter of the drill into the cutting speed desired; (4) set the drill for the nearest available speed.

Formula: $$\text{R.p.m.} = \frac{CS}{\frac{1}{4}D}$$

Example.—To find the r.p.m. for a carbon-steel drill $\frac{5}{8}$ in. in diameter, to cut soft machine steel.

Solution.—(1) Carbon-steel drill is to be used.

(2) To cut machine steel with a carbon-steel drill, the recommended speed is one half that for high-speed drill, or 40 ft. per min.

(3) $$\text{R.p.m.} = \frac{40}{\frac{1}{4} \times \frac{5}{8}} = \frac{40}{\frac{5}{32}} = \frac{40}{0.156} = 256$$

(4) Nearest spindle speed is, say, 230.

31. The Use of Cutting Oils.—It is a well-known fact that the use of some kind of cutting lubricant and coolant when cutting the metals used in machine shops, with the exception of cast iron, makes for greater production, better finish, and longer life of the cutting tool. In ordinary lathe turning, and in shaper and planer work, cutting oil is not used because the advantages to be obtained from using enough oil do not compensate for the untidiness. In drill-press work, however, it is necessary to use a lubricant in order not to tear the surface of the holes, drilled or reamed or tapped, and also not to ruin the cutting tool.

In drilling or otherwise machining cast iron a cutting oil or compound is not necessary because the chips break easily, and the graphite in the casting acts to reduce the friction. The mixture of chips and fluid often clogs the drill or other cutter and it is always very dirty.

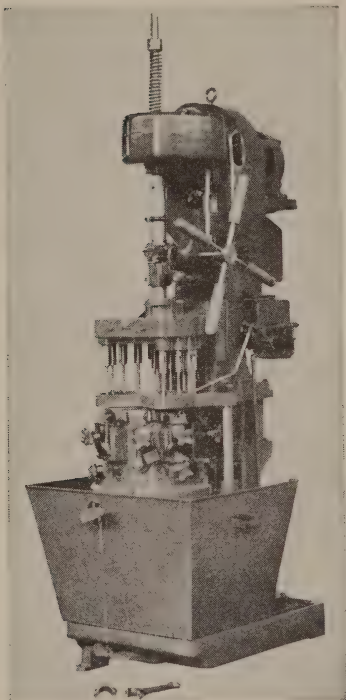


FIG. 37.—Shows a modern production-drilling setup, with multiple-spindle head and indexing-drill jig, also cutting-lubricant system and chip pan. (*Courtesy of The Cincinnati-Bickford Tool Company.*)

Lard oil is the original cutting oil and is still highly prized, but it is expensive. Sulphur added to lard oil has an advantage in drilling hard or tough material. Oil manufacturers make a sulphurized mineral-lard cutting oil which is recommended for the more difficult drilling.

For machining stainless steel a cutting compound made of two parts sulphurized cutting oil and one part carbon tetrachloride is recommended.[1]

For ordinary drilling there are a number of soluble oils on the market which when mixed with from 10 to 20 parts water make very satisfactory lubricants and coolants.

CUTTING LUBRICANTS USED IN DRILLING, REAMING, AND TAPPING

High-carbon Steel.—Lard oil or a reliable soluble oil.
Low-carbon Steel and *Wrought Iron.*—Lard oil or soluble oil.
Unannealed Steel and *Hard Spots in Cast Iron.*—Turpentine.
Malleable Iron.—Soda water or soluble oil.
Aluminum and *Copper.*—Kerosene or kerosene and lard oil mixed.
Brass and *Bronze.*—Dry or a flood of soluble oil.
Cast Iron.—Dry, never use any cutting oil when drilling cast iron.

[1] W. L. WOODSON, in *Modern Machine Shop.*

32. High-duty Upright Drill with Coolant System.—In Fig. 37 is illustrated a worth-while arrangement where a considerable amount of heavy steel drilling must be done. To keep the cutting oil off the floor and from splashing on the operator, a steel chip pan may be obtained for either the round- or box-column machine. The bottom of the pan is perforated and permits the cutting oil to flow back into circulation. When necessary, the chip pan may be easily emptied. A separate motor-driven pump is used which will, if desired, deliver a maximum volume of the cutting oil regardless of how slow the drill is running.

Questions on Drills and Drill Grinding

1. How is the drill held when grinding by hand, is it placed on the hand rest, or held in the hand? Why?

2. How is the drill grasped with the right hand?

3. What angle does the center line of the drill as properly held make with the face of the grinding wheel? Why not 45 deg.? Why not 30 deg.?

4. Why is the drill held with the cutting edge up and in a horizontal position?

5. How is the drill moved against the wheel to "back off" the cutting edge? Why not give it a twisting motion?

6. What do you mean by fulcruming the drill in the left hand?

7. Why must care be taken to have plenty of water available when grinding a drill?

8. If a properly ground drill is held perpendicular to a flat surface, what angle will one of the cutting edges make with the surface?

9. How much clearance has the cutting edge of the drill?

10. What part of the twist drill is the lip? The point? The land?

11. What is the effect of too much lip clearance? Of not enough lip clearance?

12. How can you tell by looking at the point of a drill whether or not the drill has been given sufficient lip clearance?

13. Has the drill any other clearance?

14. What is "rake" on any cutting tool?

15. What governs the amount of rake on a twist drill?

16. Why cannot a set rule be given for the speeds and feeds of drills?

17. What does the squeak of a drill indicate?

18. What do you mean by the land of the drill being worn away? What causes this? How do you repair the drill?

19. How many revolutions per minute should a ¾-in. drill be run to give a cutting speed of 35 ft. per min.?

20. State two advantages of the spiral flute.

21. On what kinds of work is a straight-fluted drill used?

22. How may a twist drill be ground to have the effect of a straight-fluted drill?

23. State two advantages of using a cutting compound when drilling steel.

24. When is turpentine used as a cutting lubricant?

25. What is the advantage of an oil-tube drill? When is it used?

26. State how you would make a flat drill 1½ in. in diameter.

27. What is the purpose of thinning the point of a drill?

28. What care should be taken when thinning the point?

HOLDING THE WORK

33. Drill Jigs (Fig. 38).—In most commercial drilling the work is held in a jig. A jig is a device made especially for

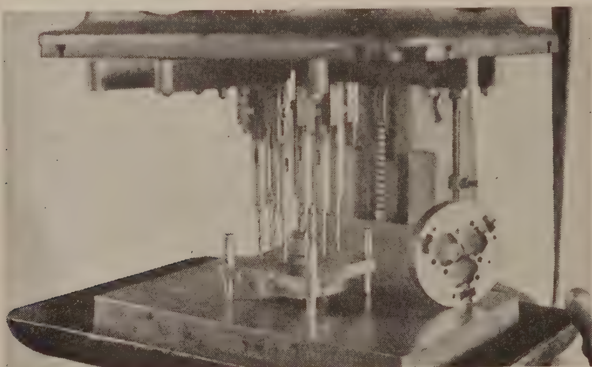


FIG. 38.—Shows the setup of a multiple-spindle drill (Fig. 8), also the jig used for drilling the body of a lathe chuck, shown at the right.

holding the work and guiding the cutting tool while drilling (and often while machine reaming and tapping). It has hardened steel bushings, through which the drill is guided so that the holes are accurately located in the work.

The double bushing or "slip bushing" (*c*, Fig. 39), is provided when the jig is used for reaming and the "loose" bushing may be removed from the "fixed" or "tight" bushing to permit of entering the reamer. Sometimes a second loose bushing is provided to guide the reamer.

Where two or more different sizes of holes are to be drilled it is customary to use a multiple-spindle drill, or to set up a gang drill (see Fig. 7) or even several machines with the drills or other cutting tools in proper sequence in the respective spindles, and pass the jig from one spindle to the next.

In the job illustrated in Fig. 38, for example, there are six of the largest holes, three of the next size, and one of the smallest. As shown in the figure, all the holes are drilled at one time in the multiple-spindle drill, but if no such machine is available, a three-spindle drill press, or three single-spindle machines could be used. Six holes would be drilled under

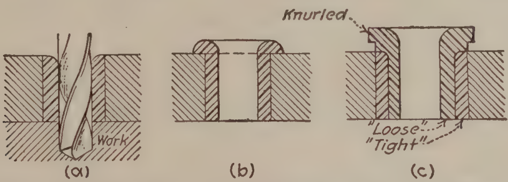


FIG. 39.—Types of jig bushings. (*a*) Flush bushing, (*b*) Flanged bushing, (*c*) Slip bushing.

one spindle, three under the next, and the smallest hole under the third.

In the larger tool-making departments the holes for the jig bushings are bored to the ten-thousandth of an inch in *jig borers.* A jig borer is a precision-built drilling and boring machine resembling a drill press. It is provided with a compound table of extreme accuracy, and other facilities for adjusting and machining the work within limits of less than the ten-thousandth of an inch.

In the absence of a jig borer, jigs may be bored in a lathe,[1] or in a milling machine, or in a drill press provided with a precision compound table (Fig. 4).

Jigs vary in cost from a few dollars to several hundreds of dollars, depending on the number and location of the holes, the accuracy required, and the size of the jig. The jig is used in manufacturing numbers of duplicate pieces. It is one of the most important of the rapid-production tools in that it saves

[1] Face-plate Work, Chap. XI, Machine Tool Operation, Part I.

the time of laying out and also the extra expense of drilling to a layout.

For run-of-shop jobs, tool making, and model work, jigs are not available. The work must first be laid out and then either held against a stop or clamped in some manner and drilled.

Generally speaking, it calls for rather more intelligence and skill to set up the job in a vise or on the table, and drill the holes to layout, than is involved in the use of a jig, consequently it is more interesting. It is important that every machinist shall be able to lay out and set up the work and drill the holes accurately without the use of a jig. An example of laying out, a description of clamping accessories, and a few hints on clamping the work follow.

34. Laying Out for Drilling.[1]—The process of laying out work for drilling consists of indicating by means of intersecting lines the positions of the centers of the holes to be drilled. At the point of intersection a slight prick-punch mark is made, and using this as a center a circle indicating the size of the hole is scribed with a divider. If the surface on which the layout is to be made has been machined a coating of blue vitriol solution may be applied and allowed a moment to dry. The lines scribed on this surface will show very distinctly. Chalk rubbed well into the unfinished surface of a casting will serve the same purpose. A simple example is given here to illustrate two methods of laying out.

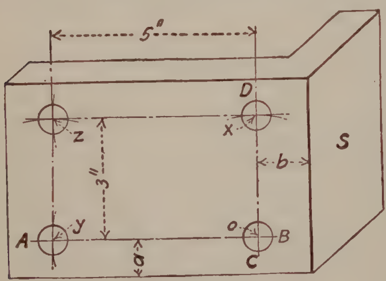


FIG. 40.

35. Example of Laying Out.—Lay out and drill four ⅝-in. holes, symmetrically located, in the face of an angle plate as per dimensions given in the sketch (Fig. 40).

1. Measure the width of the plate, subtract 3 in., and divide by 2 to obtain the distance a.

[1] See also Chap. XIII, Part I.

2. Place the angle plate on a suitable parallel on a surface plate and with the surface gauge scriber set the distance a above the parallel, scribe the line AB.

3. Measure the height of the angle plate, subtract 5 in., and divide by 2 to obtain the distance b.

4. Adjusting the surface gauge to the distance b above the parallel and placing the angle plate on surface S, square up line AB if necessary and scribe line CD.

5. The point of intersection of the lines AB and CD is the center o of one hole. Make a slight indentation at this point with a prick punch.

6. Set a divider to 3 in. and on o as a center scribe an arc intersecting the line CD at x. Make a slight prick punch mark at x. This is the center of the second hole.

7. Set the divider to 5 in. and with o as a center scribe an arc intersecting the line AB at y, and with x as a center and the same divider setting scribe a fairly long arc at z. Make a prick punch mark at the intersection of the arc at y and the line AB. This is the center of the third hole.

8. Carefully set the divider to 3 in. once more and with y as a center scribe another arc at z intersecting the arc already scribed. Make a prick punch mark at the intersection of these two arcs. This is the center of the fourth hole.

9. Set the divider to $\frac{5}{16}$ in. and with o, x, y, and z as centers scribe the $\frac{5}{8}$-in. diameter circles to indicate the positions of the four holes.

Another method of finding the centers of the four holes is as follows: After line AB is drawn, set the scriber of the surface gauge 3 in. higher and draw line through zx, and after line CD is drawn set the scriber 5 in. higher and draw line through yz. Which method is more practicable depends upon the location of the holes and the size of the work and the available tools. The given example serves merely to illustrate the methods.

Whoever drills these holes will make larger indentations at the centers with a center punch. By the time the job reaches him, the circles may have become more or less obliterated

and the rescribing should be done from a *prick-punch mark* rather than from a *center-punch mark.*

When the surface on which the layout is to be made is *unfinished,* for example, cast iron without the scale removed, a series of half a dozen or more small center-punch marks around the circle will serve to make the layout plainer (see *a*, Fig. 41). Take care to locate the marks exactly on the line, or they are worse than useless.

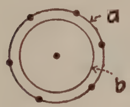


FIG. 41.

It is a good plan for the beginner when laying out holes he is to drill to scribe also from each center a circle somewhat smaller than the finished size of the hole to help in gauging the central position of the spot made before the drill cuts its full diameter (see *b*, Fig. 41). The real need of this is illustrated in Fig. 49.

36. The Use of Clamps and Stops.—All drill-press work, except the heavy pieces, should be either clamped to the table,

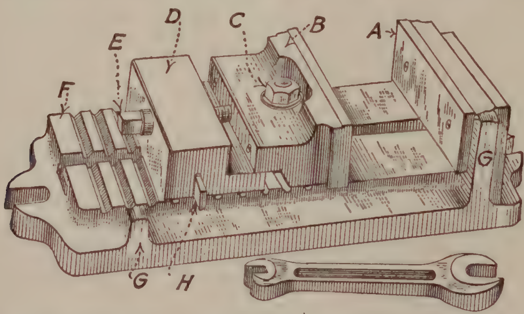


FIG. 42.—Drill-press vise. (*Courtesy of The Skinner Chuck Company.*)
A, solid jaw; *B*, movable jaw; *D*, backing block. To clamp work move *B* close to work and tighten *C*, but not too tight. Bring backing block *D* as close to *B* as will permit strip *H* to settle in nearest groove milled across the face *F* of the base. Tighten *E* and then tighten *C* this time securely. The faces *G* are finished square with the bottom to permit of using the edge of the vise as a seat if so desired.

or located against a stop. A flat clamp or similar piece makes a suitable stop (see Fig. 50). When a vise (Fig. 42) is used to hold the work, the vise should be clamped to the table or located against a stop. A jig also should be located against a stop. *Never, under any conditions, should the work be held by hand against the force of a revolving drill or other cutting tool.*

As a matter of fact, a stop is sufficient for most jobs, and in many cases is better than a clamp. It allows the work to move a little and "find its own center," and there is less likelihood of inaccurate alignment with the drill point. This is especially true when the spot has been gouged with the chisel (see Fig. 49).

If the work is fairly high, and a stop is used, have the stop high enough to counteract the tendency of the work to tip. If the work tips, the hole will be incorrect. In many jobs it is best to spot the hole, full diameter of the drill, when against the stop, and then clamp the work before drilling the remainder of the hole.

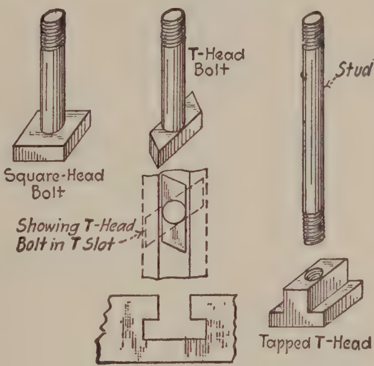


FIG. 43.—Bolts.

The success of any job that must be clamped to the table of any machine such as the shaper, drill press, boring mill, or milling machine; the faceplate of a lathe, or the platen of a planer, depends almost entirely on the manner in which it is clamped.

37. Bolts.—The worktable is provided with enough T slots to enable the operator to locate, conveniently, the necessary bolts for the stops and clamps.

The square-head bolt (Fig. 43) is satisfactory for ordinary clamping purposes, but to place it in position it must be pushed along the T slot from one end. The T-head bolt is placed by simply dropping the head lengthwise in the slot and turning it to the right, and is especially convenient when clamping inside of castings which would otherwise have to be lifted over the bolt. Many prefer the tapped T head, the stud of which may be removed and the head pushed along the slot under the casting to the desired position. Studs of various lengths may be used as needed, requiring only a comparatively small number of heads.

38. Clamps.—The *flat clamp* or "*strap*" (Fig. 44) is provided with a bolt hole (usually elongated) somewhat nearer the front end or work end. The front end is usually beveled as shown.

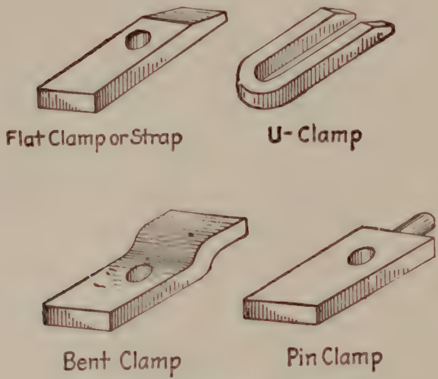


FIG. 44.—Clamps or "straps."

The *U clamp* may be removed from the bolt without removing the nut. It is also very convenient for purposes of adjustment.

39. Clamping Blocks.—The block under the outer end of the clamp may consist of a piece of handy scrap metal of the

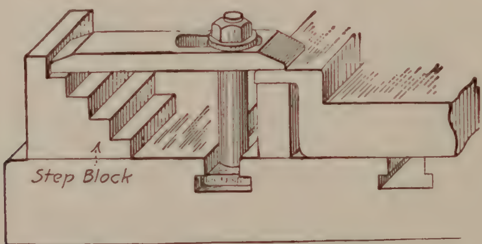


FIG. 45.—Shows use of step block.

required dimensions, or if of considerable height, suitable pieces of hardwood may be employed. Have the wood of sufficient cross section to give the needed stiffness, and arrange it under the clamp so that the pressure will be exerted *lengthwise of the grain*, and it will not crush. Figure 45 shows a

step block which is very useful. Both bases are finished and either may be used.

40. Shims.—A shim is a piece placed between the table and the work or for that matter between any two pieces or parts for purposes of adjustment or to give support. A shim may be rectangular or tapered slightly, and may be of metal, wood, or paper. Usually, however, a shim is considered as a thin piece of metal, while the heavier pieces are called "packing blocks."

41. Hints on Clamping.—1. A clamp should be properly placed and the clamping block must be the correct height

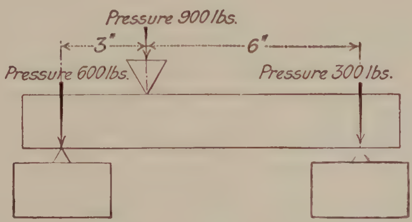


FIG. 46.—Shows a mechanical principle which should be applied when clamping work.

or the work will become loosened, with probable damage to both work and machine.

2. The clamping bolt should be placed as close to the work as conditions will permit. By the principle of levers the pressures on the work and on the clamping block are inversely proportional to their distances from the bolt. This is illustrated in Fig. 46.

3. The clamp should have a firm seat on both the work and the clamping block. The block should be at least high enough to bring the clamp parallel to the surface on which the work rests. It may be a trifle higher to insure against an edge contact.

4. The clamp must not be placed over a part that will spring under pressure until a shim or packing block is placed under that part. (See Fig. 45.)

5. Many pieces are spoiled owing to carelessness in cleaning the parts against which the work seats or is clamped. When

a piece is to be clamped in a vise, or against an angle iron or similar tool, care must be taken to clean away all chips and dirt.

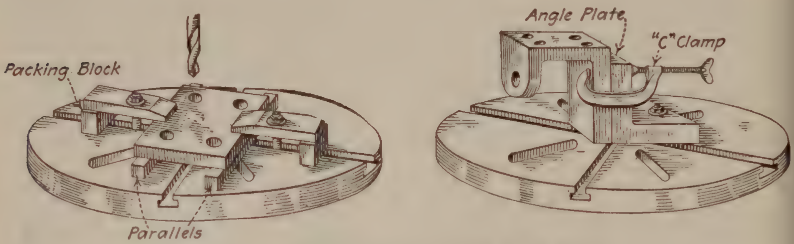


FIG. 47.—Holding work on drill-press table.

6. Never use a nut without a washer.

7. The selection of the wrench, the way it is held and *controlled*, and the judgment as to force used are indications of a mechanic's skill. (Don't "bark" your knuckles because of an uncontrolled wrench!)

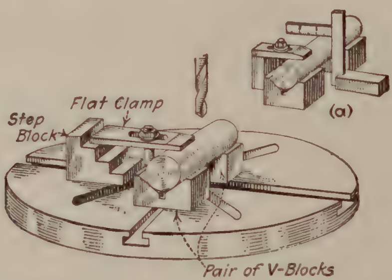


FIG. 48.—If a cylindrical piece is not too large it may be clamped in a vise; if this is inconvenient it may be clamped as shown. In either case, when setting up have the work clamped lightly with the center-punch mark as nearly over the axis of the cylinder as may be judged by eye. Then, holding a square on the table and against the cylinder, roll the work until the measurement between the blade of the square and the center-punch mark equals one-half the diameter of the work. Finally, tighten securely.

8. Oil the threads of the bolt or nut when dry.

9. Avoid using bolts that are much too long, and never use a bolt with only three or four threads catching in the nut.

10. Return clamps, bolts, and all other clamping accessories to the place where they belong. This is only fair to all concerned.

11. *A Very Important Precaution.*—When setting up for drilling holes through the work, make sure that the work is so arranged as to permit the drill to go through without drilling into the vise or the table or the parallels.

42. Examples of Drilling Setups.—Figure 47 shows methods of clamping work for drilling that are self-explanatory. Figure 48 illustrates a cylindrical piece held in V blocks and also the method of arranging the center punch mark exactly over the axis of the cylinder, or "central."

Questions on Holding Work

1. Examine the table of the drill press. Have several holes been drilled in the table top? Examine a drill vise. Has the drill been allowed to go through the work into the vise? Is carefulness or carelessness indicated?

2. What is the first care when setting up a drilling job?

3. Why is a stop usually sufficient for holding a vise? Why is it better for most work than a clamp?

4. Why is it necessary to use either a stop or a clamp?

5. Do the same principles apply to pieces not held in a vise?

6. If the work is fairly high, how are the stops arranged? Why two stops?

7. On what shape of work is the V block a convenient holding device? What angle with each other are the sides of a V block?

8. How is the V block secured to the table? How is the work held in the V block?

9. When is an angle iron a convenient tool for holding work? How is it fastened to the work table?

10. How is the work fastened to the angle iron?

11. What is a C clamp?

12. What care must be taken when applying a clamp?

13. Certain pieces are often supported by parallels and then clamped? What are parallels? Why are parallels used?

14. What is the advantage of a T-head bolt?

15. When clamping a piece of work why should the bolt be placed near the work?

16. Why is a packing block used under the clamp? How high should it be? Why?

17. What is a U clamp? What advantages has it?

18. What is a pin clamp (finger clamp) used for?

19. What do you mean by "shimming" a piece of work? What is the difference between blocking and shimming?

20. Why must the work be solid under the clamp? If the part where the clamp is applied overhangs, what must be done before clamping?

21. What are the objections to springing the work when drilling? How may it be avoided?

22. Make a sketch of a piece properly clamped showing the work, the bolt, the clamp, and the packing block.

23. What is the use of a washer? Should a nut ever be used without a washer? Give reasons.

24. How far should a nut be screwed on a bolt? Give reasons.

25. What are the advantages of a jig?

26. In your opinion when is it profitable to make a jig?

27. For what reasons, do you think, it is more expensive to drill to a layout than to use a jig?

43. Hints on Drilling.—1. Always examine a drill for size and sharpness before using it.

2. It often happens, through ignorance or carelessness, that a drill is used after it becomes dull, which causes the land to wear away for a distance back from the cutting edge. The diameter of the end of the drill is reduced, thus making the drill bind and squeak. It will be necessary to grind off the damaged end and then sharpen the drill.

3. Examine the job or the blueprint or both to determine the tools, bolts, clamps, etc., to use. Get these things together without making extra trips to the toolroom or elsewhere.

4. Have the shank of the drill and socket, or of the chuck, clean, dry, and tight in the spindle.

5. Be sure the setup is arranged so the drill will clear as it goes through the work, and not cut into the parallels, table, or vise.

6. Sometimes the condition of the drill, dull or with uneven lips, or the lips not ground to the proper angle with the axis, will cause the drill to wabble. Also, an uneven surface where the drill starts may cause the drill to run away from the center and to wabble. Forcing the feed, before the drill gets a chance to start evenly, will cause these troubles. To have the drill properly sharpened, and all other conditions right, and then to start the drill carefully will save time in the end.

7. A drill will "follow" a hole already made, and many times it is a good plan to drill a hole, say 1/8 in. in diameter and about 1/4 in. deep, to keep the larger drill from running.

8. When the drill "breaks through" at the end of the cut, it has a tendency to "dig in," especially when drilling thin pieces, and also when drilling through a cylinder at right angles to the axis, or into another hole at right angles. Such pieces should be clamped down, and, especially when hand feed is used, care must be taken or a broken drill will result. The tendency to dig is greatly increased by lost motion in the thrust bearing between the spindle and sleeve.

9. When drilling small pieces, and thin pieces especially, it is often more convenient to place them on a suitable piece of board. Set the depth gauge to allow the drill to go through the piece but not through the board. Such pieces may be stopped from turning by a nail driven in the board or they may be held in a wrench.

10. A squeak indicates undue friction. The cause should be looked for immediately and the fault corrected. Occasionally when drilling cast iron, it is advisable to rub a little oil or grease on the *lands* of the drill.

11. When a machine is overworked, it will "groan." A dull cutting tool, a chip under the cutting edge, a lack of lip clearance, and overfeeding are frequent causes. Throw out the feed at once and proceed to find and correct the fault.

12. Read carefully on page 34 the causes of spoiled work and broken drills due to faulty grinding.

44. Drilling the Hole.—Be sure that the drill is the right size, sharp, and securely held. If the work is not clamped, a stop must be provided.

Align the point of the drill carefully with the center-punch mark, start the machine and make a spot half or two thirds the diameter of the drill. Back the drill away from the work and note if the spot is central with the scribed circle. If not central, (*a*, Fig. 49), chip one or more shallow grooves *b* on the heavy side. A drill will go toward the least resistance

and chipping away stock on the heavy side will tend to make the drill cut toward that side. This operation may have to be repeated. Watch carefully and be sure the spot is central before it is the full diameter of the drill, (*c*, Fig. 49).

When a drill is properly ground, and operated at the correct speed and feed, the chips should appear as illustrated in Fig. 50. As the hole becomes deeper the chips break up more or less while being forced out. When the depth of the hole is several times the diameter of the drill, the removal of the chips becomes more difficult and it is often advisable to slightly increase the feed and decrease the speed as this gives a greater freedom of chip movement. Sometimes it is necessary to remove the drill from the hole to clean the chips (and if drilling steel to apply the cutting compound). A magnetized file is very useful for removing chips from the hole.

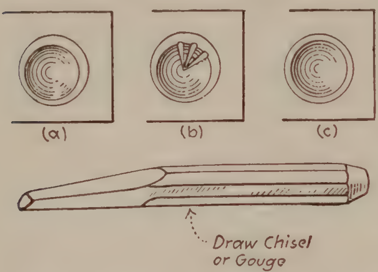


FIG. 49.—Shows use of gouge to draw the spot to center.

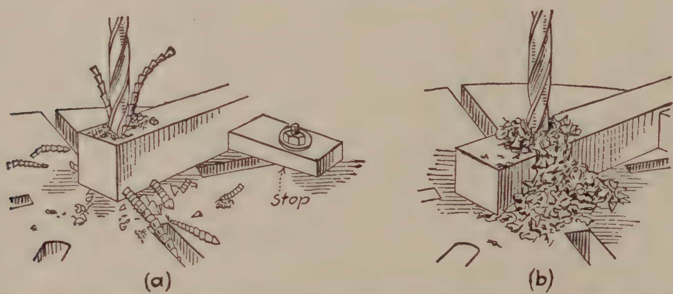
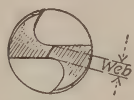


FIG. 50.—Shows appearance (*a*) of steel chips and (*b*) of cast-iron chips when properly sharpened drill is used. Shows, also, the use of a stop to keep the work from swinging around as the drill revolves.

If, when drilling steel, the drill is removed from the hole, *great care must be taken when the drill is re-entered that a chip is not lodged between the point of the drill and the bottom of the hole.* When this happens the drill will ride on the chip, and

if the feed is thrown in, the machine will be subjected to an enormous overstrain, and, if continued, either the machine or the drill will be broken. Always start the feed by hand, make sure the drill is cutting, then throw in the power feed.

When all conditions are right a fairly deep hole may be drilled straight. If, however, a hard spot or a blowhole is encountered, or if the work is not properly seated or held, or if the drill is improperly ground or dull, the hole is likely to "run." One can usually tell when a drill or other cutting tool is not acting properly by the "feel," by the sound, or by the appearance of the chip.



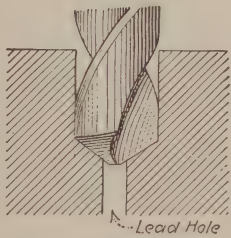


Fig. 51.—Following a lead hole or pilot hole.

45. Drilling Large Holes.—The larger the drill the greater the thickness of the "web" between the flutes and consequently the wider the "point" or "dead center." The dead center of the drill has a very ineffective scraping action rather than a keen cutting action, and to feed efficiently a drill, say 1½ in. in diameter, in a 20-in. drill press will unduly strain the machine. In such a case it will save time and trouble to thin the point of the drill as described on page 33.

Some machinists prefer to drill a lead hole (Fig. 51) of a diameter equal to about the thickness of the web of the larger drill. It is very necessary to drill this hole accurately to layout because the larger drill will surely follow the small hole. Do not drill a lead hole much larger than necessary or the following drill may chatter and drill out of round or at least spoil the "mouth" (top) of the hole. In any event do not crowd the drill, that is, feed it too fast, when starting.

Do not brush the chips carelessly about and do not permit the cutting compound to flood the table and floor. When through using the bolts, clamps, or other tools, clean them and put them where they belong. An expert workman is neat and orderly.

Questions on Drilling

1. Is the drill properly sharpened? Have the cutting edges been given sufficient clearance?

2. If the hole is to be drilled through the piece, what precaution must be taken?

3. If the hole does not go through the piece, how may the depth be gauged on the spindle?

4. Is the "depth" of a drilled hole measured from the point or from the corner? *Ans.* From the corner.

5. When, in general, is it necessary to use a clamp to hold the work? When is it better to use a stop? Why is it nearly always best to use one or the other? When may it be unnecessary?

6. How is a straight-shank drill held?

7. How is a taper-shank drill held? Why should the taper be clean and free from oil? How is the drill removed?

8. What is the difference between a prick-punch mark and a center-punch mark? When is each used?

9. When is chalk or whiting used in a layout? When is blue vitriol solution used in the layout?

10. Why are prick-punch marks sometimes made in the circles showing size and position of holes?

11. If two or more holes are to be drilled in a piece securely clamped to the table, how may they be located in turn under the drill without loosening the clamps?

12. State two things that will cause a drill to wabble.

13. If the center-punch mark in the layout is practically true, why will not the drill always start true and cut true?

14. If the spot shows out of center with the layout, a gouge chisel should be used. On which side of the spot is it used? How many chisel cuts should be made? How deep?

15. If a piece is clamped to the table before it is located exactly under the drill, is it necessary to adjust the table before drilling the hole if a draw chisel is used? Give reason?

16. How may chips be removed from a hole?

17. Is a lubricant used when drilling cast iron?

18. Does a squeak indicate proper or improper conditions? Why?

19. If a fairly deep hole is being drilled in cast iron, how may oil be used?

20. It is sometimes necessary to remove the drill from a partly finished hole. If a steel chip lies under the point of the drill when it is run back into the hole, what is the result? What is the remedy?

21. When does a machine "groan?"

22. Why is it best always to feed by hand until you are sure the drill is cutting?

23. If no chip is under the drill and the machine groans, what is indicated?

24. What is indicated when the extreme outer corners of the cutting edges of the drill wear away rapidly? What will happen if this fault is not immediately corrected?

25. Either one of two faults may cause the lips to chip. What are these two faults?

26. A very common fault in grinding causes a drill to split up the web; what is it?

27. How is the proper cutting speed of a drill determined?

28. How many revolutions per minute are necessary to cut 30 ft. per min. with a 7/8-in. drill? To cut 40 ft.?

29. How many revolutions per minute are necessary to cut 40 ft. per min. with a drill 1 1/4 in. in diameter?

30. How many revolutions per minute are necessary to cut 35 ft. per min. with a 1/4-in. drill?

31. What lubricant is used when drilling soft steel or wrought iron? When drilling unannealed steel? When drilling aluminum?

32. How does lost motion in the spindle thrust bearing account for breakage of drills?

33. How is a twist drill ground for drilling brass? Why?

34. What is meant by thinning the point of a drill? When is it advisable?

35. When is it advisable to use a pilot drill?

CHAPTER III

OTHER DRILL-PRESS TOOLS AND OPERATIONS

REAMERS

46. Introduction.—It is practically impossible to drill a hole to the exact size of the drill. Therefore to obtain a hole of standard size, round and smooth, it is practical to drill or bore to $\frac{1}{32}$ in. undersize and then machine-ream. If greater accuracy is required, it may be bored or machine-reamed to within $\frac{5}{1000}$ in. of size and then hand-reamed.

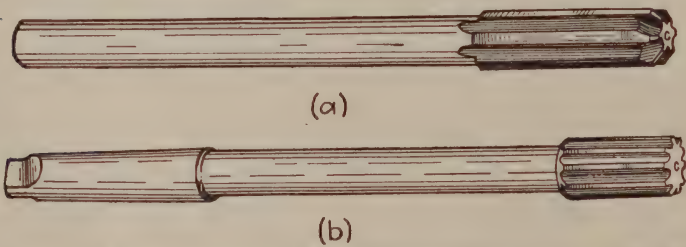


FIG. 52.—Machine reamers. (*a*) Straight-shank rose reamer; (*b*) taper-shank fluted reamer.

Reamers are made of either carbon-tool steel or high-speed steel; in hundreds of sizes; for general or specific purposes; in various types and kinds; straight, and in all standard and many special tapers. They are made with straight or taper shanks for machine use, and with squared shank for hand reaming, and many sizes are available in either expansion or adjustable types.

Spiral teeth in a reamer cut more freely, tend to prevent chatter and to prevent catching if there is a longitudinal slot or keyway in the hole.

The work is held for reaming in the same ways as for drilling. In fact, it is the usual practice to follow the drill with the

reamer under exactly the same conditions that the drilling was done.

47. Chucking or Machine Reamers (Fig. 52).—There are two types of machine reamers, rose reamers and fluted reamers. In the *rose reamer*, the teeth are beveled on the end, backed off, and cut only on the end. The lands[1] are nearly as wide as the grooves and are not relieved (backed off). The flutes or grooves are provided for conveying oil to the cut and chips away from the cut. The rose reamer tapers slightly smaller toward the shank (about 0.001 in.) to prevent binding; it does

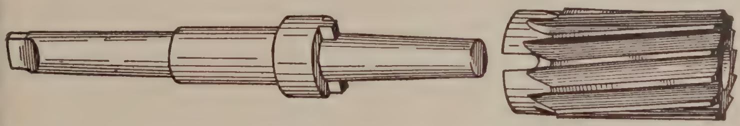


Fig. 53.—Shell-reamer arbor and shell reamer with spiral teeth.

not cut a particularly smooth hole but is very useful to bring the hole to within a few thousandths of size, when it may be finished with the hand reamer. Rose reamers, therefore, are usually made 0.003 to 0.005 in. under nominal size.

The *fluted reamer* has more teeth for a given diameter than the rose reamer. The lands are narrower, and are backed off the whole length. The front ends of the teeth are beveled or rounded and then relieved. It is a valuable finishing reamer when extreme accuracy is not required.

Both the rose reamer and the fluted reamer are made with either straight or taper shanks. It is not usually advisable on account of the extra cost to buy taper-shank reamers under 7/16 in. diameter; and it is not usually good practice to buy straight-shank reamers of over 1 in. in diameter on account of the difficulty in holding them.

48. Shell Reamers.—For reasons of economy, many manufacturers prefer the shell reamers and arbors illustrated in Fig. 53. These reamers are made in either rose-reamer style or fluted-reamer style and the arbors with either straight or

[1] *Land.*—In reamers, milling cutters, etc., the width of the top of the tooth is called the land.

taper shanks, and differ in no particular respect from the ordinary solid reamer except that one arbor may be fitted to a number of reamers, and when a reamer is worn out it may be thrown away without discarding the arbor.

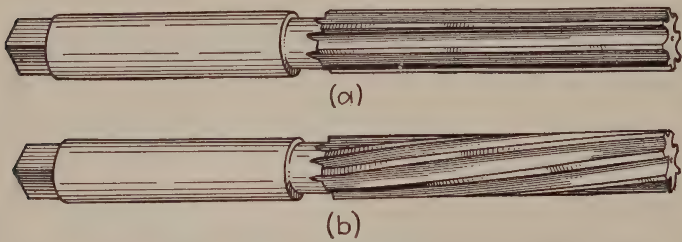


FIG. 54.—Hand reamers. (*a*) Regular; (*b*) with spiral teeth.

49. Hand Reamers (Fig. 54).—Where a particularly accurate hole is required it is first drilled, bored, or machine-reamed to about 0.005 in. undersize and then hand-reamed.

A hand reamer is essentially a finishing tool, a scraping tool, and is ground straight for nearly the whole length of the teeth. It is slightly tapered, smaller toward the end, for a distance about equal to its diameter, to permit of its entering the hole to be reamed. The teeth are relieved a very little for clearance. The shank end is machined square to receive the wrench. *The hand reamer should never be operated by mechanical power.* Care should be exercised to start it true and keep it straight. It is often advisable to start the hand reamer when aligned and steadied by the dead center of the lathe or a center placed in the drill-press spindle, as the case may be. *Do not leave over* 0.005 *in. for a hand reamer.*

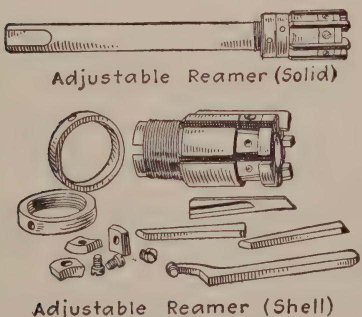


FIG. 55.

50. Adjustable Reamers (Fig. 55).—Probably the most efficient kind of reamer for any purpose is the adjustable-blade

reamer. The best types of these reamers can be adjusted to sizes within a considerable range over or under nominal size; often a valuable feature. While they cost more than the solid type of reamer, the fact that they may be easily sharpened and quickly adjusted to an exact size, and their corresponding

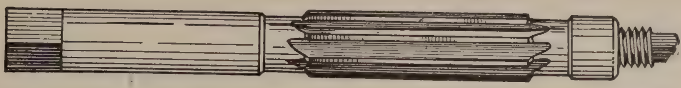


FIG. 56.—Expansion hand reamer. (*Courtesy of Morse T. D. & M. Company.*)

long life, make them a particularly efficient tool. These reamers are made in all standard sizes, either hand or machine, with the body and shank in one piece or of the shell-reamer variety.

51. The Expansion Reamer.—The body of the expansion reamer (Fig. 56) is bored slightly taper and slitted to permit a slight expansion (about 0.005 in. in a 1-in. hand reamer and proportional amounts in other sizes ¼ in. and over). A

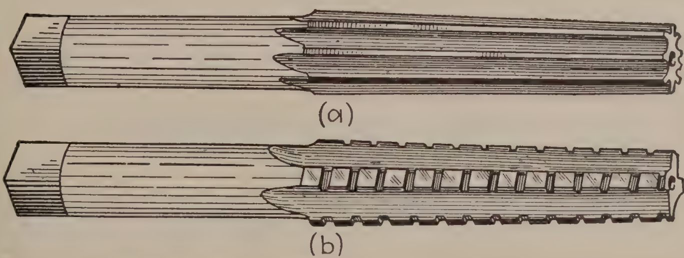


FIG. 57.—Hand reamers for taper holes. (*a*) Finishing; (*b*) roughing.

apered plug, threaded through the end (guide) and squared or a wrench, is the expander. This reamer is not meant for in oversize reamer, or for an adjustable reamer; it is meant to give longer life to a reamer for finishing standard-size holes.

52. Taper Reamers.—Taper reamers, both for roughing nd finishing (Fig. 57), are made for all of the standard sizes f tapers. The end of the shank of the hand reamer is cut quare to receive the wrench, and the reamer should always

be turned by hand. As the chips do not fall out readily a taper reamer should be removed often and cleaned.

By reason of the shearing cut such as is given to a reamer by the spiral flutes, there is less strain upon the reamer, less clogging with chips, and a smoother and more accurate hole results. This is especially true with steep-spiral taper reamers for use in machines (Fig. 58). Rough with the coarser tooth and finish with the finer tooth reamer. Feed slowly.

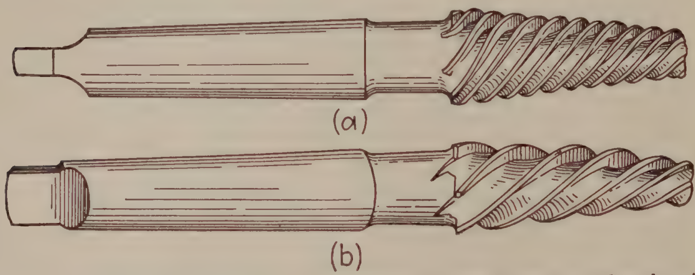


FIG. 58.—Machine reamers for taper holes. Have steep left-hand spiral teeth. (*a*) Finishing; (*b*) roughing.

53. High-speed Reamers.—Cutting tools made of high-speed steel will cut at least twice as fast and often four or five times as fast as similar tools made of carbon steel. It follows that where it is practicable to obtain the increased speed, it is profitable to use high-speed cutting tools. For example, in production work where considerable machine reaming is to be done, it is economy to use high-speed reamers. An adjustable machine reamer with high-speed steel blades has the advantage of the tough steel body.

54. Emergency Reamers.—A drill may be used as a reamer to give a satisfactory result if the corners are slightly rounded with an oilstone. Run at fairly high speed and feed slowly.

A small-size reamer that will work well and can be easily sharpened may be quickly made from a piece of drill rod of the size desired. Cut off to length, square the end, and round the corner somewhat. Then reduce the diameter a thousandth or two except for an eighth of an inch or so from this end, either by filing or with emery cloth. Now bevel the end 45 deg. or

more leaving about half of it, back off the single cutting edge a very little and harden and temper. Grind and oilstone the flat beveled surface, oilstone the rounded cutting edge a trifle and the reamer is ready to use. Feed slowly as there is only one cutting edge.

55. To Avoid Chattering of Reamers.—Chattering is a more or less rapid vibration of the work or the tool which produces a wavelike unevenness in the surface being finished. It may be caused by improperly adjusted bearings, too much spring of the tool or work, too wide a cut, or too much clearance on the tool.

To lessen the tendency of chattering, reamers are *increment cut*,[1] that is, the teeth are unequally spaced. With such teeth chatter marks cannot occur at the same rate for succeeding teeth—cannot *synchronize*—and, therefore, the tendency is for the reamer to cut smooth. Also, in hand reamers, the faces of the teeth are radial or slightly ahead of radial to give a scraping cut, and the lands are relieved only a small amount.

To further lessen the tendency to chatter, the teeth of reamers may be cut on a spiral. In the case of a spiral-cut reamer, the spiral should be left-hand, that is, the twist should be opposite that of a twist drill, otherwise the tendency is for the reamer to pull into the hole, and this would tend to increase rather than to diminish the trouble.

By reason of the shearing cut such as is given to a reamer by the spiral flutes, there is less strain upon the reamer, less clogging with chips, and a smoother and more accurate hole results. This is especially true with steep-spiral taper reamers.

56. Hints on Reaming.—1. A burr on the tooth of a hand reamer will spoil the hole. When any reamer is obtained from the toolroom, feel along the cutting edge or the land of each tooth, and if any burr is noticed, oilstone it off.

2. Always use lard oil or other suitable cutting compound when reaming steel or wrought metal.

3. It should be emphasized that *never under any circumstances* should a reamer be turned backward.

[1] For fluting increment-cut reamers see p. 296.

4. Oil is not used as a cutting lubricant when reaming cast iron. It is very often advisable, however, to put oil on the lands of a rose reamer to reduce the friction in the hole and prevent scoring.

5. Do not attempt to start a reamer on an uneven surface. The reamer as it starts tends to go toward the point of least resistance and if not started true will not ream a straight round hole.

6. To avoid tearing at the beginning, bring the reamer to the edge of the hole before starting it, and feed carefully.

57. The Operation of Reaming.—It depends upon the degree of accuracy and finish desired whether or not a hole should be reamed at all and also whether it should be merely machine-reamed or finished with a hand reamer. For example, bolt holes or cap-screw holes, whether body size or tap-drill size are not reamed, while holes for dowel pins, pivot pins, hinge pins, etc., must be reamed. Further, a hole into which a mandrel is to be used for other machine operations, for instance, the hole in a pulley or in a gear blank, must be reamed. When the hole is fairly long in proportion to the diameter and an extra smooth surface is not required, a fluted machine reamer will give the desired result. When a high degree of accuracy and finish is desired, a hole had best be hand-reamed. It is first machine-reamed with a fluted reamer or rose reamer 0.002 to 0.005 in. undersize which leaves the correct scraping chip for the hand reamer.

A hole that is to be reamed is drilled with a "reamer drill" which is usually $\frac{1}{64}$ or $\frac{1}{32}$ in. "undersize" (less than the finished diameter of the hole).

It is customary immediately to follow the drill with the reamer, especially if the work is clamped, to insure alignment. The speed for reaming is usually somewhat less than for drilling, to avoid any tendency to overheat and ruin the cutting edge. The feed should not be crowded or the reamer may tear the surface of the hole. Be sure the reamer runs true and take care in starting the cut, otherwise a chatter may develop which will spoil the mouth of the hole. If the reamer

chatters, stop the machine and then start very slowly, pulling the belt by hand if convenient.

If the hole is to be hand-reamed, it may be well to put a center in the drill-press spindle to align and steady the reamer until it is well started. As the reamer is turned with a tap wrench (Fig. 65, page 67) and cuts its way into the hole, follow it up with the center but do not crowd it; feed by hand. Assistance will probably be necessary.

58. Duplicating a Drilled and Reamed Part.—When, as frequently happens, it is desired to duplicate a flat piece having two or more holes already drilled and reamed, a quick accurate method is as follows: Obtain a drill, the size of the reamed hole, to be used as a "spotting" drill, a machine reamer of the desired size, also a "reamer drill" $1/64$ or $1/32$ in. smaller. Clamp or otherwise arrange the two pieces with the one to be drilled and reamed in position under the piece already reamed, with the first hole aligned under the spotting drill in the machine spindle. Spot this hole, then remove the spotting drill and put in the reamer drill (undersize drill), and drill the hole. Then ream with the machine reamer. After reaming and before proceeding to the next hole, insert any suitable pin or plug through the two pieces to keep them in exact relationship while the next hole is being spotted, drilled, and reamed. If three or more holes are to be made, it will be wise to use a second plug as this will prevent any shifting of either piece while the other holes are being made.

Questions on Reamers and Reaming

1. It is assumed that the hole has been drilled. Select a reamer of the proper size. When is a machine reamer used as a finishing reamer?

2. If it is not to be used for finishing the hole, how much undersize is it made? Why?

3. How is a taper-shank reamer held in the spindle?

4. If the shank is too small to fit the spindle hole, what do you do?

5. Why is it necessary to wipe the taper clean and dry?

6. How is a straight-shank reamer held?

7. What are the advantages of the taper-shank reamer? Of the straight-shank reamer?

8. Is it necessary to clamp or "stop" the work when using a machine reamer? Give reasons.

9. What part of the machine reamer does the cutting? Where is the tooth clearance? What other clearance has a machine reamer?

10. What is the use of the flutes in a machine reamer?

11. How much metal is usually left for a machine reamer to remove? Why not $\frac{1}{16}$ or $\frac{1}{8}$ in.?

12. What is the cutting speed of a machine reamer as compared to a twist drill? How do the feeds compare?

13. When is a lubricant used in reaming?

14. What are the advantages of facing around the hole before machine-reaming?

15. How should a reamer be started? If it chatters what is indicated?

16. If a machine reamer squeaks when used in cast iron, what does it indicate? How may it be avoided?

17. If several holes are to be drilled or reamed through two pieces clamped together what precaution should be taken?

18. What is a machine reamer? Fluted reamer? Rose reamer?

19. What is an adjustable reamer? What are its advantages?

20. What is a shell reamer? What are its advantages?

21. How may a drill be used for a reamer if no reamer of the size is available?

22. How may a small size reamer be quickly made from a piece of drill rod?

23. What is a hand reamer? Why is part of the body ground slightly tapered?

24. Should a hand reamer be operated by mechanical power? How may it be used in the drill press?

25. When using a hand reamer in a drill press or lathe, why is it wise to "follow it up" with the center? How is this done? What precaution should be observed?

26. State at least three precautions that should be observed when using a reamer.

27. Why does a reamer tend to follow the hole already made?

28. If the work is *clamped*, and the drilled hole is not exactly in line with the machine spindle, what will be the result when the hole is reamed?

29. Explain the process of duplicating a flat piece with two or more holes.

59. The Counterbore.—This tool is used to face around a hole in order that a nut or a bolt may set square with the hole; or to enlarge a hole to a given depth, as for the fillister head of machine screws and cap screws (see Fig. 17, page 21).

The standard solid counterbore (Fig. 59) consists of *the guide* (sometimes called the teat or the pilot) which is the size of the original hole; the *cutter head*, which is the size of the enlarged hole, and on the end of which the cutting "teeth" are formed; *the necked portion* which in the counterbore is

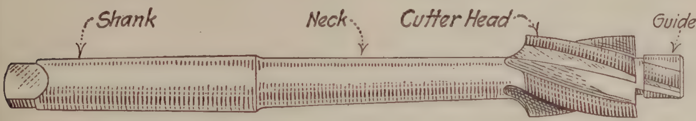


FIG. 59.—Solid counterbore with taper shank.

fairly long to permit of enlarging a hole to a considerable depth if desired; and *the shank* which may be straight or taper. Grooves are cut either straight or spiral in the head to form the upper faces of the cutting teeth. These grooves usually extend the whole length of the head to provide for the removal of chips, and to provide also a way for lubricating the cut. The teeth are backed off about 10 or 12 deg. to give clear-

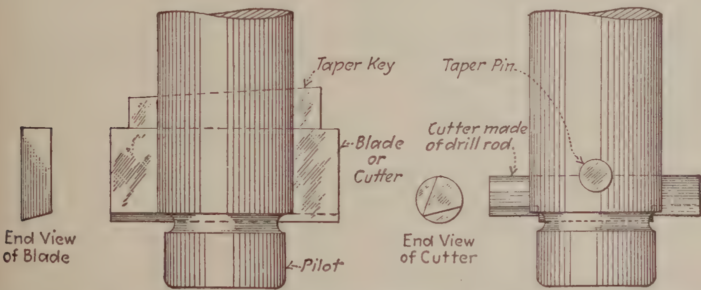


FIG. 60.—Two types of homemade counterbores with removable blades or cutters.

ance to the cutting edges. The cutter head is slightly tapered, smaller toward the shank, so that it will not bind.

Counterbores are made solid in the smaller sizes (Fig. 59) and usually with removable cutters or blades in the larger sizes (Figs. 60 and 61). In any case the cutting edges are at right angles to the axis of the counterbore in order to cut a *flat* surface.

A counterbore should have at least two cutting edges. They should be carefully and evenly ground in order to balance the cut. Sometimes one tooth of a counterbore with a wide cut is ground to cut only in the middle and a little deeper

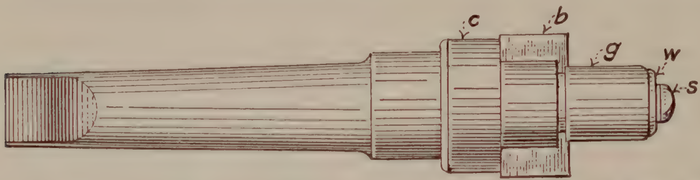


FIG. 61.—Combination counterbore. (*Courtesy of the Cleveland Twist Drill Company.*)

The large part *c* of the cutter head is a hardened-steel collar forced into place after the slot for the blade *b* is cut. It projects somewhat over the slot and is ground true on the face. The blade is centered by a turned projection which fits the collar and is held square against the ground face of the collar by the guide bushing *g*, the washer *w* and the screw *s*. The bushing is slotted to fit over the blade and is hardened and ground. Various sizes of blades and bushings are quickly interchangeable.

than the other tooth. This is to break the chip, and narrow the width of cut. It should, however, be so ground as to allow each tooth to do its share.

The counterbore is not designed for extremely accurate work; therefore the body is usually made a trifle (0.003 to

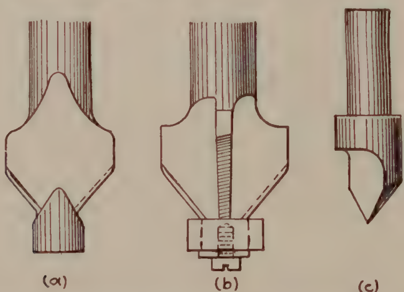


FIG. 62.—Types of countersinks for flathead screws. The included angle is 82 deg., *not* 60 deg. as in a center reamer.

0.005 in.) over the nominal size, and the guide is made one- or two-thousandths under the size of the hole to be enlarged so that it will not bind. Oil the guide before using so that it will not rough up.

A cold chisel is much cheaper to make and much easier to sharpen than a counterbore, and it is often desirable to chip off the scale around the hole before spot-facing or counterboring cast iron.

To avoid any danger of overheating and drawing the temper of a counterbore, run it at a somewhat slower speed than for drilling a hole of corresponding size, and apply the cutting lubricant freely.

60. The countersink may be differentiated from the counterbore in that it is used to enlarge the end of a hole to a cone shape, as for a flathead machine screw or a wood screw. The terms "center reaming" and "countersinking" are both applied to the operation of making the center holes in work to be machined "on centers." The combination drill and countersink is the best tool to use for this operation. An important fact should be kept in mind—the included angle of a center hole is 60 deg. and the included angle of the countersunk hole for the head of a wood screw or a standard flat machine screw is 82 deg.; do not get the 82-deg. countersink and the 60-deg. center-reamer mixed.

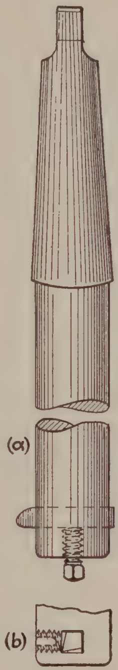


FIG. 63.—Boring tool for drill press.

Three different kinds of countersinks for screw-heads are illustrated in Fig. 62: (*a*) two-lip with guide; (*b*) four-lip with guide bushing and provided with screw and washer for holding various sizes of bushings to fit holes of different diameters; (*c*) the cheapest and best form of countersink for small screws.

Countersinks are run at fairly slow speed to avoid chattering. Hand feed is commonly used, and plenty of cutting lubricant should be applied.

61. Boring in a Drill Press.—It is sometimes practicable to use a drill-press for boring a hole, for example, when a drill or reamer of a suitable size may not be available. Further, when a perfectly straight hole is desired and a high degree

of accuracy as to location is necessary, it is frequently drilled 1/16 in. or more undersize, then *bored*, and finally reamed. If it is understood that a reamer will tend to follow the hole already made but that a boring tool tends to go straight (cutting more from one side of the hole than from the other side if necessary), the value of boring a hole to insure accuracy of shape and of location will be apparent.

Drill-press boring tools are made in many varieties and sizes. Figure 63 illustrates a common type: The cutting tool is held in position by a setscrew in the end of the bar as at (*a*), or by a hollow setscrew in the side of the bar as at (*b*). When the boring tool is for any reason long and slender and inclined to spring, it is necessary to take light cuts.

Questions on Boring, Counterboring, Etc.

1. What is the difference between "boring" and "counterboring" a hole?

2. What is the difference between "counterboring" and "countersinking?"

3. What is the difference between a machine-screw countersink and a countersink (center reamer) for a lathe center?

4. State two cases when a boring tool may be used to advantage in a drilling machine.

5. Why should one select a boring bar as short and heavy as convenient to use?

6. Some shops provide three different sizes of counterbores for each of the most used sizes of fillister-head screws, namely, the body-size to head-size counterbore; the tap-drill size to head-size counterbore; and the tap-drill size to body-size counterbore. What is meant by these terms? What is the purpose of each of these counterbores?

7. Why do you put oil on the teat of a counterbore? Is this true when counterboring cast iron?

TAPS AND TAPPING

62. Taps.—A tap is a master tool for cutting internal threads. Several forms of taps are used in machine work, brief descriptions of which follow:

Hand Taps.—Most internal threads are cut with taps, usually in a tapping machine or with a tapping attachment in the drill press. Many threads, however, must be tapped by

hand. Figure 64 shows a set of machinist's hand taps squared on the shank end to receive the wrench (Fig. 65). Hand taps, except the sizes under ¼ in., are made in sets of three taps, called taper, plug, and bottoming. The first tap or taper tap is tapered or "chamfered" back from the end at least six threads, the plug tap is chamfered about three or four threads, while the bottoming tap is merely backed off on the

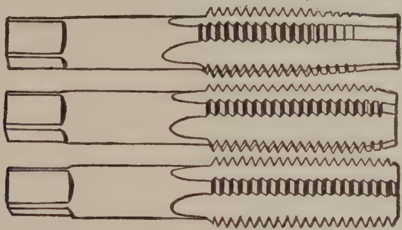


FIG. 64.—Set of hand taps, taper, plug, and bottoming.

end teeth. Taps furnished in sets are of the same diameter unless otherwise specified, so that to tap a "through hole" it is only necessary to use the taper tap. Where the hole does not go through the piece ("blind hole") it is customary to start with the taper, follow with the plug, and, occasionally, if the hole is fairly shallow, finish with the bottoming.

Machine-screw Taps.—Hand taps under ¼ in. diameter, such as 8–32, 10–24, etc., are catalogued as machine-screw taps and

FIG. 65.—Adjustable tap wrench.

are used mostly in the form of plug taps. If necessary they may be quickly ground to either taper or bottoming form.

Serial Taps.—A set of serial taps consists of three taps of varying diameters (both outside and thread-pitch diameters). These taps are distinguished from ordinary hand taps by shallow grooves (rings) cut around the shanks near the squared end (one, two, and three rings, respectively, for the No. 1, No. 2 and No. 3 taps). No. 1 tap is the smallest and "roughs out"

the thread, No. 2 takes a second roughing out, and No. 3 finishes the thread. They are useful for cutting threads in tough metal or when an especially smooth and accurate thread is desired.

A tapered tap has a uniformly tapering body or portion thereof and is used for tapping a full thread in a tapered hole. The most common example is the ordinary *pipe tap.* A tapered tap is best named for its particular purpose, thus avoiding confusion with the first tap or "taper tap" in a set of hand taps.

Tapper tap (Fig. 66) is the name given to the tap whose chief use is in a special nut-tapping machine. The shank is longer than a hand tap of the same diameter and invariably is

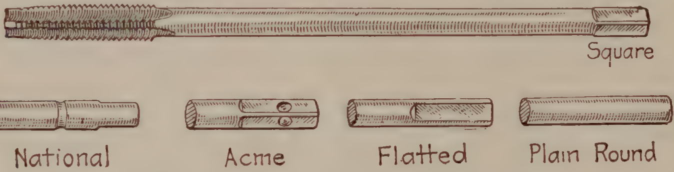


FIG. 66.—Tapper tap and forms of shank ends.

smaller than the root diameter of the thread. This is for the purpose of holding a number of nuts after tapping. When no more nuts can be held on the shank, the tap is removed and the tapped nuts slide off the shank. Usually the tapper tap is given a longer taper (chamfer) than the taper tap of a hand set, to lighten the work of each tooth. If considerable taper is given, care must be taken not to ream the hole instead of tap it.

Some manufacturers turn the first six or eight threads taper, not merely turn the outside taper, but cut the threads on a taper. This eliminates to a certain extent the tendency otherwise to ream the hole and also improves the cutting qualities of the tap and produces a "cleaner cut" thread. Also several of the straight threads are chamfered to reduce the amount of work for the successive cutting edges. Tapper taps are provided with various forms of shank ends to fit the holders of nut-tapping machines in common use.

Pulley taps are especially long hand taps for tapping the setscrew and oil-cup holes in the hubs of pulleys. The shank is long enough to reach through a hole drilled in the pulley rim which is made substantially the size of the shank and thus affords a means of aligning and steadying the tap. The "extension drill" for the hole in the hub may be made by

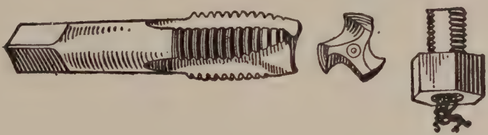


FIG. 67.—Gun tap. (*Greenfield Tap & Die Corporation.*)

soldering a straight-shank drill in a hole drilled in the end of a suitable piece of cold-rolled steel.

Machine taps are made for general use in special tap holders in drilling machines. One of the best known and most efficient holders is the Beaman and Smith holder (see Fig. 70). A plug hand tap may be used as a machine tap in a drilling machine provided with spindle-reverse gears, or in certain tapping attachments if a suitable holder for the squared shank end is provided. Do not use a chuck to hold a tap over ⅜ in. diameter because it is likely to injure the chuck.

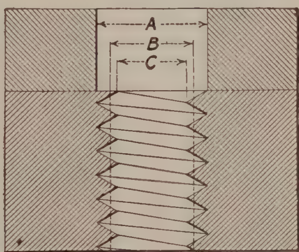


FIG. 68.—*A* is a body size; *C* is minor diameter; *B* is tap-drill size that will leave enough stock for about three-quarters of a full thread as shown.

The gun tap (Fig. 67) is very efficient when used either as a hand tap or in a machine for power tapping. Because of the shape of the initial cutting edges, which have both rake and shear, it is unnecessary to chamfer more than three or four threads, thus avoiding the tendency to ream. Further, it does not clog because the chip "shoots" out ahead of the tap.

63. Tap-size Drills.[1]—The diameter of the hole to be drilled for the threads in a nut or other inside threaded piece is *theo-*

[1] For tap-drill sizes see Table 17, page 498.

retically the minor diameter of the corresponding screw size. This will give a *full depth* of thread, and it is not practical to tap a full thread; therefore the *tap-drill sizes* are larger than the minor diameter. Three quarters of the full thread is enough to leave for tapping (see Fig. 68). An ordinary nut so drilled and tapped will break the bolt before the thread will strip. Use the following:

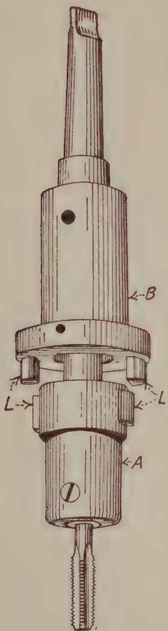


FIG. 69.—Leland tapping attachment. (*Courtesy of Pratt & Whitney Company.*)

RULE.—The size of the tap drill for American standard threads equals major diameter minus 1 divided by number of threads per inch.

Example.—$\frac{1}{2}$ in. tap—13 threads.

Solution.—$0.500 - 1 \div 13 = 0.500 - 0.077 = 0.423$. The nearest drill under 0.423 in. is $\frac{27}{64}$ in. (0.421).

64. Advantages of Tapping by Power.—Tapping by power reduces the expense and inaccuracy of tapping by hand. In addition to being much easier and quicker, it is steady and even, and effects a saving in the breakage of taps and also prolongs the life of the cutting edges. Because of the firm manner of holding and turning the tap, the thread produced is clean and true.

65. Tapping Attachments.—The spindle-reversing feature (Fig. 13) in itself is very efficient for power tapping when used with judgment and skill. However, no automatic stop being provided, the operator must reverse or stop the spindle at the proper time. It will, of course, be understood that the feed stop (30, Fig. 9) only stops the advance of the spindle and does not stop its rotation.

An auxiliary attachment, such as described in the following paragraph, when used in connection with the spindle stop practically eliminates the chances of error or accident.

66. Auxiliary Tapping Attachments.—There are, in the market, several kinds of tapping attachments provided with taper shanks to fit the drill-press spindle. Figure 69 shows a tapping attachment (Pratt & Whitney Co.) designed to be used with

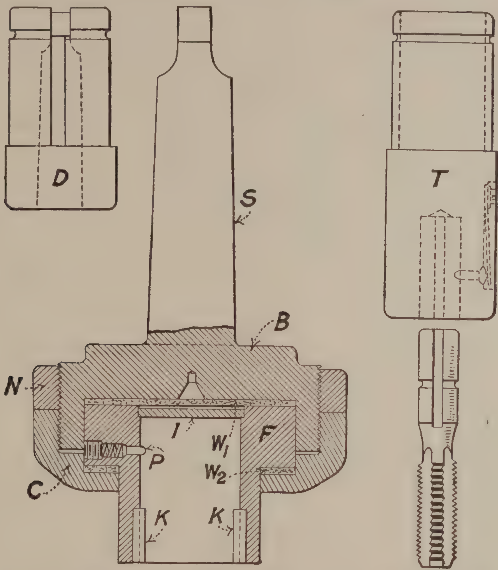


FIG. 70.—Beaman and Smith safety drill and tap holder.

S is the shank and *B* the body recessed to receive the friction socket *F*. The cap *C* screws on the body and holds the friction tap holder *F* as tight etween the fibre disk W_1 and washer W_2 as is necessary to drive the drill or ap. *N* is a check nut for securing the cap *C* in place after the friction adjustnent is made.

Special sockets, *T* and *D* as shown, are required to hold the tap and drill. aps with special shanks may be obtained from almost any tap manufacturer. rill sockets are furnished with Morse taper holes for any desired size of drill.

The sockets are inserted in the holder *F* and are kept from turning by the eys *K* and from falling out by the small spring plunger *P*. It will be observed hat the tap is held in its socket in a similar way. The thrust of the socket or *D* is against the disk *I*, which serves to protect the fibre disk W_1.

he reversing mechanism of the drill and using also the spindleeed stop (30, Fig. 9). The tap holder *A* is held up within the ody *B* of the attachment by spring tension. A slight pressure erves to start the tap, and the advancing tap pulls the spindle ith it until the stop is reached. After the spindle has stopped

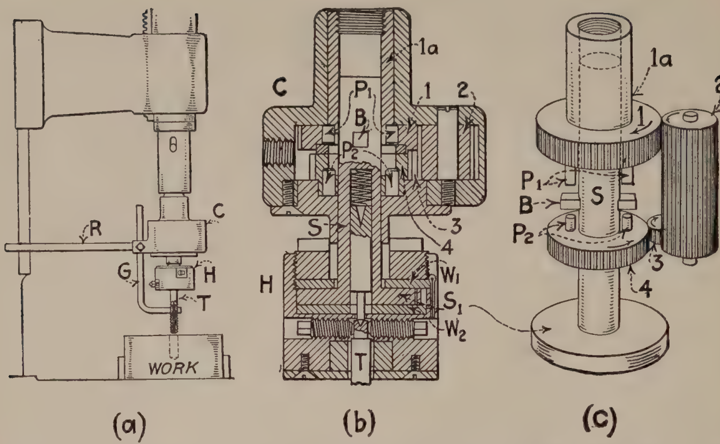


FIG. 71.—Errington automatic reverse. (*a*) Mechanism arranged in drill press. (*b*) Vertical section through reversing mechanism and friction holder. (*c*) Sketch of auto-reverse mechanism somewhat elongated for clearness.

PARTS.—*C*, casing of automatic reversing mechanism. *H*, Friction holder for tap or stud setter. *G*, Adjustable depth gage. *R*, Stop rod (prevents case *C* from turning). *T*, Tap (stud setter may be substituted). *S*, Spindle, provided with friction flange S_1. *B*, Clutch bar [end view in (*b*) side view in (*c*)]. (1), Driving gear. (2) and (3) Intermediate gears. (4), Reversing gear. P_1, Driving-gear clutch pins. P_2, Reversing-gear clutch pins. W_1 and W_2, Friction washers.

EXPLANATION.—The auto-reverse permits of rotating the spindle *S* in opposite directions with a constant forward motion of the drilling-machine spindle. A suitable shank is fitted to screw into the hub (1*a*) of the driving gear (1), and consequently this gear rotates with the drill-press spindle. As the drill press spindle is fed down, the clutch pins P_1 engage the clutch bar *B*, both ends of which project radially from the spindle *S* as shown in (*c*), and the spindle *S* rotates clockwise to drive the tap into the hole. The gage *G* serves to stop the downfeed of the gear (1) but the tap keeps on turning until the spindle *S* is pulled down, by the threading-in of the tap, far enough to disengage the clutch pins P_1, at which time the spindle *S* stops turning. As the operator raises the drill-press feed handle, the reversing gear (4) is raised to engage the clutch pins P_2 with the clutch bar *B*. This starts the spindle *S* and the tap in the counter-clockwise direction, and as the operator lifts the feed handle the tap is backed out of the hole.

The reversing gear (4) gets its motion fom the driving gear (1) through the intermediate gears (2) and (3) as shown in (*c*).

advancing, the tap still threads its way into the hole against the force of the spring until the driving pins L are disengaged and the tap ceases to revolve. Reversing the spindle serves to withdraw the tap. If the spindle stop is properly set, duplicate holes may be tapped the required depth without difficulty.

Figure 70 illustrates the Beaman and Smith safety drill and tap holder for use in a machine having a reversing mechanism.

Figure 71 shows the Errington Auto Reverse tapping chuck which is a tapping attachment with the reversing mechanism contained. This chuck requires no reversing mechanism on the drill press, as it drives the tap in, stops automatically, and backs the tap out with quick return by simply raising (not stopping or reversing) the drill spindle. It fits the socket of any drill press and can be used for right or left threads. Certain of the larger sizes have attachments for setting studs or nuts which are very efficient.

67. Tapping in a Drill Press.—1. Make the setup carefully, having the holder or attachment tight in the spindle and properly adjusted, the work so held that it cannot twist or cramp, and the tap sharp and running true or arranged to "float" in the holder.

2. Use a slow spindle speed, especially until practice has given confidence.

3. The spindle must be perfectly free to slide in the sleeve, no feed being necessary in the tapping operation except in certain cases a "follow-up" hand feed.

4. Have at hand plenty of cutting lubricant and apply it freely when tapping; provide a means of catching the surplus, however, in order to avoid wasting the lubricant and messing the machine. (Lard oil is best for steel, and soap or tallow works well for tapping cast iron.)

5. Have the work located against one or more stops so it may be able to center itself.

6. A certain pressure is needed to start the taper tap and care must be taken to make the tap "bite" or "catch the thread" and not ream the top of the hole taper. After the

tap is well started, it feeds itself and requires only to be turned. It is a good plan occasionally to turn the tap backward half a turn to break the chip, and in tapping soft material such as copper, babbitt, etc., it is necessary to remove the tap several times and clean away the chips.

7. When the hole is tapped to the depth required, reverse the direction of rotation of the tap and with a slight upward pressure on the feeding lever back the tap out. It may be

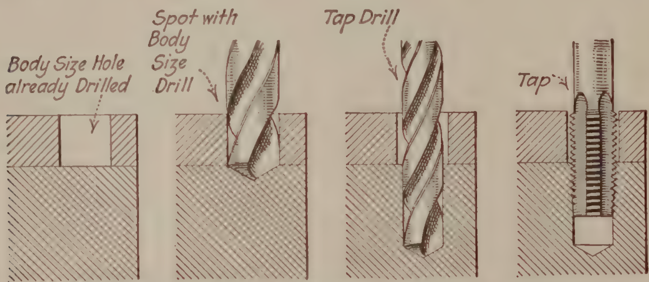


Fig. 72.—Spotting and drilling for tap. In order to tighten the top piece to the other, the screw will go through the top piece (*body-size drill*) and screw into the bottom piece after this piece has been *spotted* with the body-size drill, drilled with the *tap drill* (a given amount smaller than the body size) and then tapped.

necessary in a fairly long hole to reverse part of a turn once or twice during the tapping operation to break the chip.

68. Using a Piece Already Drilled as a Template.—Very often in machine construction, when one part is fastened to another part by screws, it is advisable to "spot" through the body-size holes drilled in one to locate the positions of the tap-size holes in the other. This operation is illustrated in Fig. 72. If several holes are to be spotted and drilled, it will be best to tap the first hole as soon as it is drilled—possibly the first two holes—and hold the pieces together while the other holes are spotted and drilled.

Questions on Taps and Tapping

1. Name the three taps in a tap set. What is the purpose of each one?

2. When threads are tapped in tough metal, what should be done to keep them from tearing?

3. What lubricant is best when tapping cast iron? Steel? Brass? Aluminum? Copper?

4. How far should a screw enter a tapped hole in order to give sufficient strength?

5. What is a "blind" hole?

6. If the effort to turn the tap is continued after it bottoms, what will be the result?

7. How do you use a scale when counting the number of threads per inch? What is a "pitch gauge?"

8. How may the pitch of the thread in a nut be determined with a whittled stick, if there is no tap or bolt to fit it?

9. What size is the largest drill that will pass through the nut?

10. What is a tap drill? What is meant by a "body size" drill?

11. Why is a tap drill smaller than the outside diameter of the bolt?

12. Why are the screws used in automobile work of finer pitch than those used in machine-tool manufacture?

13. In common practice, is the tap-drill size equal to the root diameter of the thread? Is it larger or smaller?

14. State three objections to the use of a tap drill that will give a full thread.

15. When two pieces are to be held tightly together, why not tap both pieces?

16. If it is desired to tap a slightly larger hole in a nut so it will be a free fit on a thread, how can this be done with a standard size tap?

Ans. Wrap waste around the tap.

17. Before attempting to re-tap an old nut, what precaution should be taken? Why? *Ans.* Be sure it is not case-hardened.

18. It occasionally happens that a ½-in. screw will not fit a tapped hole which appears all right. What caution must be observed when using ½-in. setscrews, ½-in. taps, and ½-in. dies?

Ans. Beware of ½–12 threads.

19. How is a tap sharpened? How is it "backed off?"

20. Explain the principle of the operation of the bevel gears and the clutch in the reversing mechanism or tapping attachment.

21. State four advantages of tapping by power.

22. Explain by sketch and description the action of an auxiliary tapping attachment by means of which duplicate holes may be tapped the same depth using the spindle stop.

23. What is the meaning of the word *template?*

THE SHAPER

CHAPTER IV

SHAPER CONSTRUCTION

69. Introduction.—The function of the shaper is, primarily, the production of flat surfaces. The work is held on an adjustable worktable or more often in a vise fastened to the worktable, while the cutting tool, which is given a reciprocating motion, that is, caused to move forward and back, peels off a chip on the cutting stroke. During the return stroke the feed operates to move the table (and work) the desired amount.

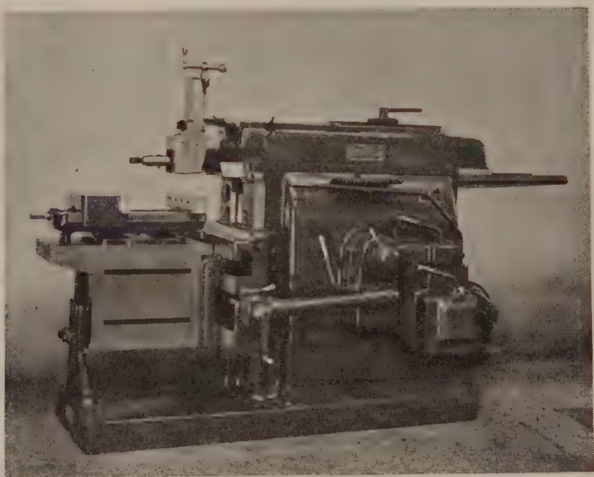


Fig. 73.—Standard 14-in. crank shaper. (*Courtesy of Gould and Eberhardt.*)

Shapers are classified as to size (14, 16, 20 in., etc.) by the maximum length of the cut that may be taken, and a standard shaper of a given size will hold and plane a cube of that size.

The crank shaper (Fig. 73), in which the tool carrier is driven forward and backward by a vibrating arm operated by a crank-pin in the main driving gear or "bull wheel," and in which the feed is transmitted to the worktable by ratchet-and-pawl mechanism, is so commonly used as to be termed standard. It should be noted, however, that the *hydraulic shaper*, Fig. 74, is becoming increasingly popular. The tools used, the work-holding methods, and the general operations are the same for either type.[1]

70. The Value of the Shaper.—The relative values of different methods of doing a job, or of the kinds of machines to use, is one of the most profitable and interesting studies in machine-shop work. For example, for a small number of pieces it may be better to plane one piece at a time in a shaper; for a larger number of pieces it may be more efficient to set up and plane several at a time in a planer. It may be cheaper and quicker to take one or more cuts on, say, 25 pieces in a shaper or planer rather than in a milling machine; on the other hand, if there are enough pieces to make the extra initial expense worth while, it probably would be much better to provide a special fixture and a special cutter, and machine them in the milling machine.

The shaper is especially adapted to small work which may be held in a vise bolted to the worktable. The toolhead is so constructed as to permit of horizontal, vertical, or angular cuts being taken. For toolroom work such as punch and die work, jig and fixture parts and on short work for other special tools or machines, the shaper is practically indispensable.

The shaper-cutting tool is easily ground the desired shape for the cut to be taken and when dull may be quickly sharpened. The ranges of stroke and position of stroke, of vertical adjustment of worktable, of feeds—lateral, vertical, and angular—together with the adaptability of the single cutting tool, serve to make the shaper more efficient for many jobs than the milling machine. This is especially true in model work or tool work involving at most only a few pieces. On the average

[1] For principles of hydraulic power transmission see Chapter XVII.

shorter cuts within its capacity the shaper is more efficient than the planer for the following reasons: It costs less to buy, it takes less power to run, occupies less space in the shop, is about one third quicker, the work is more easily adjusted, and generally speaking less skill is required in operation.

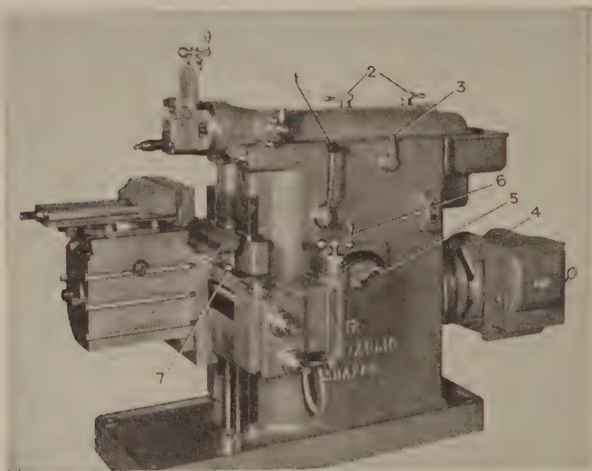


Fig. 74.—Hydraulic shaper. Hydraulic features are numbered; for other part names and functions see Fig. 75. (*Courtesy of The Rockford Machine Tool Company.*)

1. A single control starts and stops the ram instantly, also selects high or low cutting-speed range. Duplicate lever, on opposite side of column, for convenience.
2. For adjusting length and position of ram stroke (without stopping ram or using wrench or handle).
3. A touch of the finger reverses direction of ram instantly.
4. Motor is direct connected to hydraulic unit which, with oil reservoir, is housed within the column.
5. The desired cutting speed, stepless from zero to maximum, is obtained by setting this lever.
6. For adjusting the amount of hydraulic table feed.
7. This lever controls the direction of table feed.

A wide variety of very accurate work may be easily and quickly accomplished in the shaper if the machine is in good condition, clean, and well oiled, and the operator understands its construction and the principles of its operation.

71. Parts of Shaper.—On the following pages a standard crank-driven shaper is illustrated (Fig. 75) and described. In connection with your job in the shaper, study the illustration (and machine) and text carefully and learn the names and functions of the parts.

A machinist who can intelligently run a lathe made by a manufacturer in Cincinnati will have no particular difficulty in operating a lathe made by another company in Hartford. These lathes may have different features in design but, in principle, they are alike in construction and operation. So with shaper work, a shaper is built for certain operations and the machinist who understands the construction of a given standard shaper will have no trouble in understanding quickly the constructional features, that is, the functions of the various levers, handles, etc., of any shaper.

72. Crank-shaper Driving Mechanism.—In machine construction, circular motion may be "changed" to reciprocating motion in several ways; for example, through a cam, an eccentric, or a crankpin. In the standard shaper the crankpin is used. The *reciprocating* motion (forward and return "stroke") is given to the ram by the *circular* motion of the large gear, called the crank gear or the "bull wheel," acting through a *crankpin* and vibrating arm, or *rocker arm*. This mechanism is called the *drive* of the shaper.

The lengths of shaper jobs vary, and as the length of stroke should be only about ¾ in. longer than the cut to be taken, provision is made to change the stroke to any length from zero to maximum. The drive will be explained first, and then the means of changing the length of stroke.

The bull wheel revolves fast or slow, according to the speed for which the machine is set. Referring to Fig. 76 (and also to Fig. 78), the bull wheel carries a crankpin C, and as the bull wheel revolves, the crankpin describes a circular path and moves a large rocker arm M. The rocker arm is hinged at its lower end, and the upper end is connected to the shaper ram by the link A and the clamp block B. If it were not for the slot in the rocker arm, the crankpin would lock the bull wheel and rocker arm together and neither could move. If the crankpin itself fitted the slot, without the wide bearing surfaces provided by the sliding block D, it would soon have flat surfaces on opposite sides and cause lost motion and a heavy pounding noise. If it were not for the link A or a similar

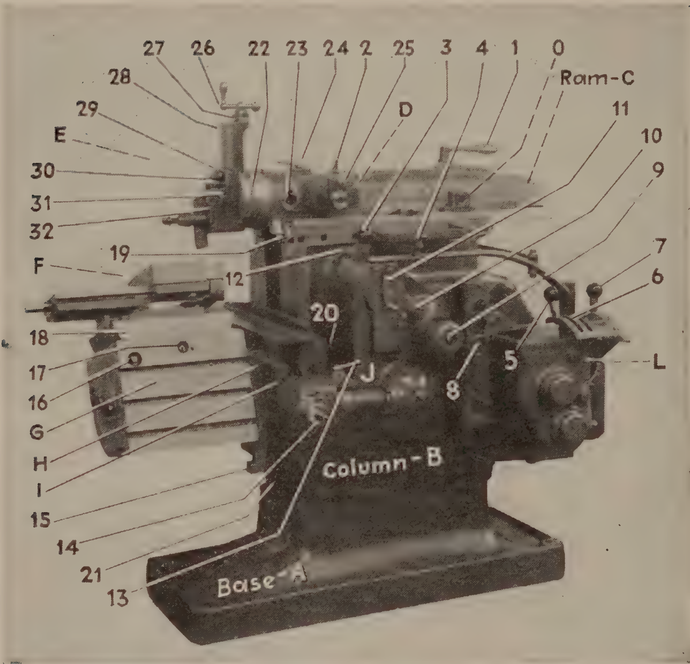


FIG. 75.—Standard 14-in. Shaper. (*Courtesy of The Hendey Machine Company.*)

PARTS OF THE SHAPER

Index to Unit Names

A. *Base*, pan-shaped to keep oil off the floor.

B. *Column*, main support for the operating mechanism. The top is machined and scraped to form a flat bearing for the ram.

C. *Ram*, carries the toolhead. Cast in cylindrical form to give strength and stability; has, in operation, a reciprocating motion on the column. Both the *length* of the stroke, and the *position* of the ram with reference to the work are adjustable.

D. *Power downfeed mechanism*, automatic feed to toolhead slide (28).

E. *Toolhead*, holds the tool and contains the downfeed screw; is swivel in construction to permit the tool to be fed at an angle.

F. *Vise*, work holder on a swivel base.

G. *Worktable*, bolted to saddle; is provided with Tslots. When constructed to swivel on the saddle, and also to be tilted, as shown (16), (17), and (18) it is called a universal table.

H. *Saddle*, the table connection to the crossrail. Has three bearings on the crossrail, with dovetail tongue having taper gib.

I. *Crossrail*, held in any desired position on vertical surfaces machined and scraped on the front of the column, carries the saddle and worktable, also part of the table feeding mechanism. It is gibbed in the space between the column uprights.

J. *Carrier plate* for cross-feed mechanism.

K. *Gear-reduction motor*, with flange mounting. (Located on the left side of shaper and not shown in this illustration.)

L. *Speed-change gearbox;* gears run in oil.

M. *Rocker arm* (not shown, see Fig. 78).

W. *Crank gear* or "*bullwheel*" (not shown, see Fig. 78).

O. *Distributer* for automatically oiling the ram ways, crankpin, and block, and the feed mechanism.

device, the ram would have to travel in an arc instead of horizontally back and forth.

73. Adjustment for Length of Stroke.—To get the various lengths of stroke it is necessary to change the position of the crankpin from "on center" (no movement) to the limit of "off center" (maximum stroke). This means that the crankpin must be carried on a block that may be moved toward, or away from, the center of the bull wheel.

Referring to Fig. 77 (also to Fig. 78), it will be observed that the crankpin C, carrying the sliding block D, is fastened in the dovetail block E into which the screw S is threaded. This screw is fixed in its position, that is, it cannot move axially (lengthwise), and therefore when it is turned, the block E moves. Thus the crankpin may be moved along a radial slide in the bull wheel by turning the shaft (4) which serves to turn the screw S by means of the bevel gears G and H. Consequently, as the shaft (4) is turned (by means of a handle

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Index to Part Names

1. *Binder lever* for securing ram to rocker arm M.
2. *Ram-positioning shaft* for operating ram-positioning screw (first loosen binder lever 1).
3. *Start-and-stop clutch lever.*
4. *Safety lock* for start-and-stop lever.
5. *Speed-change gear-shift lever;* eight speeds of the ram are provided—four direct and four through the back gears.
6. *H plate* for speed-lever positions.
7. *Back gear in-and-out lever.*
8. *Push button* for motor.
9. *Shaft for changing length of stroke of ram.*
10. *Index dial for length of stroke of ram*
11. *Handle for regulating the amount of cross-feed.*
12. *Contact spring for feed cam roll.* (See 22, Fig. 86.)
13. *Lever for engaging cross-feed*, forward or reverse.
14. *Table-feed screw*, for moving the saddle and table on the crossrail. The feed-screw nut is attached to the rear wall of the saddle H. For hand feed, put the handle on the squared end of the screw.
15. *Stop* for cross horizontal alignment of the tilting top of the worktable. (Stop for alignment of plain face of table is on other side of table, not shown.)
16. *Wormshaft* for rotating the worktable.
17. *Binding screw for the tilting top of worktable.*
18. *Tilting top of worktable.*
19. *Felt inserts* to wipe off dirt and retain oil.
20. *Crossrail clamping bolts* (located on both sides of crossrail); used to secure rail to column after adjustment up or down. It is imperative that these bolts are loosened slightly before raising or lowering the table, and tightened when the table is in position.
21. *Screw for raising or lowering crossrail*, moved by miter gears (the shaft and handle are on the further end of the crossrail).
22. *Swivel plate for head*, has graduations in degrees for angular settings.
23. *Pilot hole for geared wrench* to bind swivel head to ram.
24. *Downfeed clutch lever.*
25. *Lever and sector for regulating amount of downfeed.*
26. *Hand-feed crank for downfeed.*
27. *Graduated micrometer collar* on downfeed screw.
28. *Toolhead slide;* has binder (not shown) to keep slide from creeping when taking a cut.
29. *Clapper box*, with angular adjustment.
30. *Clamping bolt for clapper box.*
31. *Hinge pin* for tool block.
32. *Tool block*, or *clapper block*, holds tool post. This block and the clapper box (29) are together known as the *apron*.

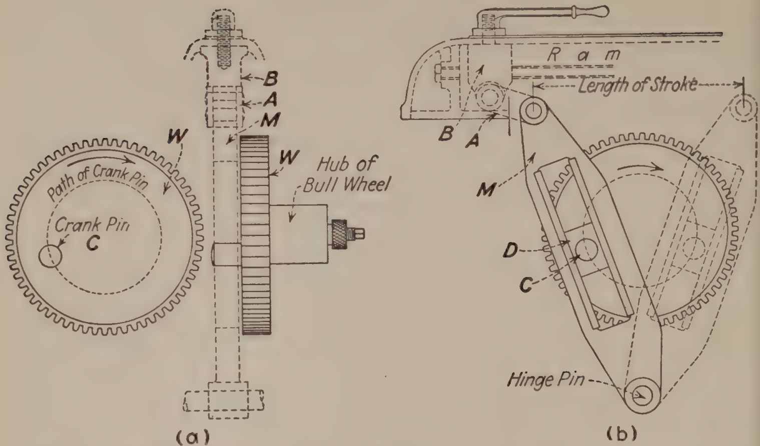


FIG. 76.—Drive of crank shaper. In (*a*) is shown the path of the crank-pin *C* as the bull wheel *W* revolves. In (*b*) is shown the position of the rocker arm *M* at each end of the stroke. The sliding block *D* acts as a bearing for *C* in the long slot in the rocker arm. The rocker arm is connected to the clamp block *B* by the link *A*.

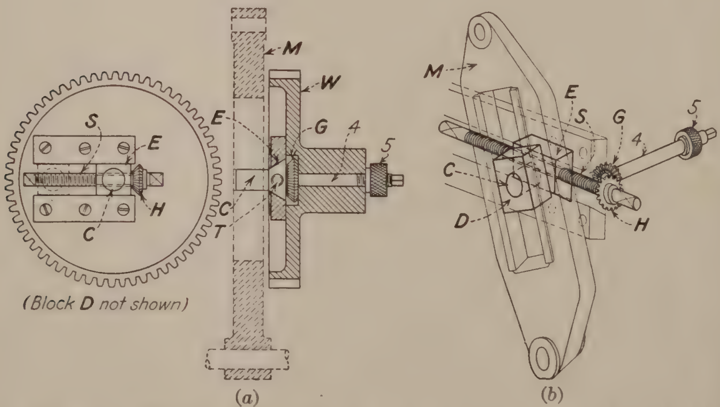


FIG. 77.—Diagram (*a*) and sketch (*b*) to show the relation of parts of the mechanism for changing the length of stroke. Loosen (5) and, with handle on squared end, turn shaft (4). This turns *G*, *H*, and *S*, and moves block *E* and crankpin *C*. In the diagram (*a*), the crankpin *C* is shown on center, and the dotted lines indicate its extreme position off center.

supplied) the crankpin is moved toward, or away from, the center of the bull wheel, depending upon the direction the shaft is turned.

An index plate and pointer, or a dial and pointer, are provided for reading the length of stroke. The highest number the pointer reaches indicates, in inches, the length of stroke for which the shaper is set. The shaft (4) is locked automatically in some shapers, and in others by tightening the knob (5).

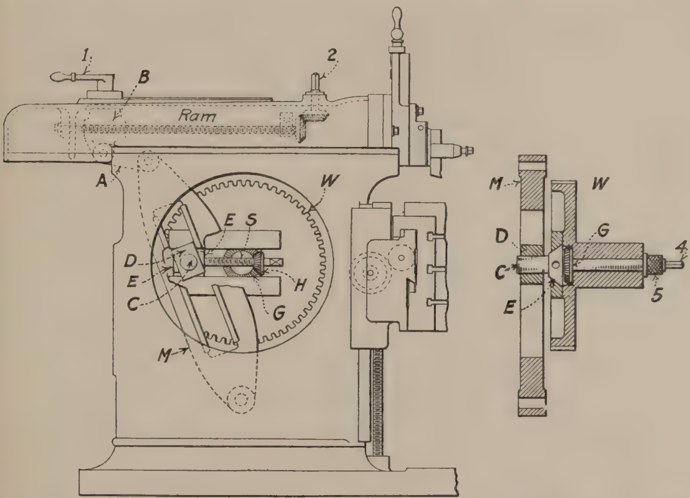


FIG. 78.—Shows the shaper driving mechanism, from the bull wheel W to the ram, and also the mechanisms for changing the *length* of stroke and *position* of stroke.

NOTE: To set the length of stroke in the older designs of shapers, pull the belt by hand, or turn the handwheel if motor-driven, and move the ram to that *end of stroke* at which the pointer will be over the number on the side of the ram which indicates the length of the stroke to which the shaper is set (in some shapers the *end* of the forward stroke, in others the *end* of the return stroke). Then loosen the nut (5), put handle on squared end of shaft (4), and turn until the pointer indicates the length of stroke desired; then tighten (5).

74. Adjustment for Position of Stroke.—If, after the length of the stroke is correct, the travel of the tool does not cover the work as in (a), Fig. 79, the *position* of the stroke is changed

to make it correct as in (*b*). Move the ram to its extreme forward position, next loosen the clamp block *B*, Fig. 78, by moving the handle (1), and then, by turning handle (2), adjust until the end of the tool projects from a quarter to ½ in. beyond the edge of the work. Remember, the adjust-

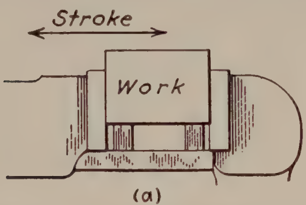


FIG. 79.—The length of the stroke is right, but in (*a*) the tool will not cover the work. In (*b*) the *position* of the stroke has been changed.

ment for the *length* of stroke should be made *before* the adjustment for position.

75. The Quick Return.—Owing to angular position of the rocker arm at the point of reversal, the ram travels faster on the return stroke than on the cutting stroke. The principle

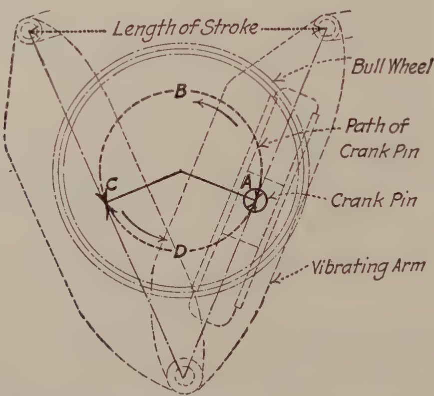


FIG. 80.—Shows principle of quick return. (Viewed from right-hand side.)

of this "quick return" is shown in Fig. 80. In the circular path of the crankpin the arc *CDA* represents the *time* of the return stroke and the arc *ABC* the *time* of the forward or cutting stroke, and the ratio (average) is about 2:3 in most

shapers. That is, it takes about one and one half times as long to make the cutting stroke as it does to make the return stroke (ratio 2:3 = 1:1½).

76. Speeds of the Shaper.—At a given speed of the driving gear a shaper will make a constant number of strokes per minute, whether they are long or short. To obtain a given

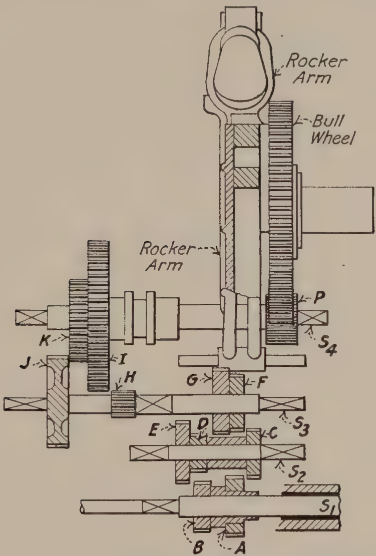


FIG. 81.—Shaper driving mechanism.

Gear Runs.

Slower Series		Faster Series	
B-E-D-G-H-I	Slowest	*B-E-D-G-J-K*	
A-C-D-G-H-I		*A-C-D-G-J-K*	
B-E-C-F-H-I		*B-E-C-F-J-K*	
A-C-F-H-I		*A-C-F-J-K*	Fastest

cutting speed per minute for the tool, the shaper must have twice as many strokes for a cut 2 in. long as for a cut 4 in. long. Therefore, to allow for the different lengths of stroke (and also for the different metals to be cut) the shaper is provided with different speeds.

In the shaper with cone-pulley drive the speed changes may be obtained by changing the belt on the various steps of the pulley. In the shaper with single-pulley drive or individual-

motor drive the different speeds are obtained through *speed-change gears.*

Shapers are provided, usually, with eight speeds, four direct through the speed-change gearbox and four through the back gears. A typical arrangement is shown in the diagram, Fig. 81.

It will be observed that the speed at which the final driven gear (bull wheel) revolves is determined by the relative sizes of the driving and follower gears in the various pairs of gears which make up the compound gear trains which serve to transmit motion from the shaft S_1 to the bull wheel. Thus in the slowest speed B is smaller than E, D is smaller than G and H is smaller than I, which makes for a reduction of speed in each pair of gears. To produce the next slowest speed, merely move a given lever. This disengages B with E and engages A with C which serves to slightly increase the speed of S_2 and this increase is of course carried on to S_3 and the bull wheel.

77. The worktable may be *fed* horizontally either by hand or by power; and may be *adjusted* vertically to provide for different jobs, which may vary considerably in height. The table is bolted to a saddle, and the saddle is gibbed to the crossrail which provides a suitable bearing surface for the horizontal (feeding) movement of the worktable when the feed screw is turned. Either a rapid traverse of the table or the desired amount of "hand feed" may be obtained by means of a crank placed on the squared end of the feed screw. The automatic feed will presently be explained. The front face of the column of the shaper is finished to form a suitable bearing surface for the vertical adjustment of the crossrail. That is, the crossrail, together with the saddle and table, may be raised or lowered. This is accomplished by means of a vertical screw operated through bevel gears by a horizontal shaft, the squared end of which is on the side of the machine. The same crank handle that is used for hand feed is used here. Clamping bolts are provided on both sides of the shaper to securely bind the crossrail to the column. Whenever the vertical adjustment of the table is made these bolts

should first be loosened, the adjustment made, and then the bolts tightened to give rigidity to the work. In the larger shapers, 16-in. and over, to give greater rigidity to the table and work under the pressure of the cut an adjustable brace is arranged from the base of the machine to the table. If the table is to be lowered, it will, of course, be necessary to loosen this brace.

The worktable is provided with T slots on the top and on both sides for the purpose of holding bolts for clamping the work or the work-holding devices. In nearly all shapers the table is permanently bolted to the saddle, but at an additional cost the manufacturer will furnish a "universal table" (Fig. 75). This table may be swiveled on the saddle plate, thus providing an angular adjustment of the work *at right angles to the direction* of the stroke. Also, the top of the table, having either hinge or swivel construction, may be given an angular adjustment *in the direction* of the stroke. These table-swiveling and -tilting features are useful when any considerable amount of angular (bevel) or taper planing must be done (see Fig. 99).

The larger shapers are now provided with *power rapid traverse* of the worktable, either by built-in mechanical means, or by an individual electric motor.

Questions on Shaper Construction I

1. In a crank shaper how does the bull wheel drive the rocker arm?
2. What is a crank shaper?
3. What is the use of the slot in the rocker arm?
4. Where and how is the crankpin held?
5. How is the screw turned to move the crankpin? Why are bevel gears used? Where is the check nut? How does it serve to hold the crankpin in position?
6. How much movement has the rocker arm when the crankpin is on center? Why? Away off center?
7. What is meant by the stroke of a shaper? Cutting stroke? Return stroke? What is the maximum length of stroke of the shaper on which you are working? What size shaper is it?
8. Is there a link between the hinge pin and the vibrating arm, or between the arm and the ram? What is the use of the link?
9. What is the reason for the slot in the top of the ram?

10. How is the rocker arm connected to the ram? How is the position of this connection changed? How does it affect the "position of the stroke?" Why are bevel gears used between the handle and the screw?

11. Explain the "quick return" of the shaper ram.

12. What clamping bolts must be loosened before adjusting the table vertically? How much should they be loosened? Why?

13. How is the elevating screw oiled? How are the thrust bearings oiled? How often?

14. What amount of vertical adjustment of the table is possible?

15. What is the value of the table brace support?

16. Why does turning a screw move the worktable horizontally? How is this screw turned by hand? What is this movement called?

17. How are the various speeds obtained in the shaper? What is the need of having several speeds? Are back gears provided in a shaper? Give reason.

18. On what kinds of work is the shaper particularly useful.

19. Give several reasons why the shaper is better than a planer for small work.

SHAPER FEEDS

78. The Feeding Mechanism.—The feed screw of the shaper is *fixed* in its position, that is, it may be revolved but does not move laterally. Therefore the large nut, into which the feed screw is threaded and which is fastened to the worktable, moves the table when the screw is turned either automatically (power feed) or by hand.

The automatic feed is obtained by causing the feed screw to make part of a revolution, and how much it moves (more or less feed) is governed by the action of a pawl[1] which engages a ratchet wheel (Fig. 82) which is either fastened to the screw or transmits its motion to the screw through gears.

The pawl *operates* once, and *gets ready* to operate again, during each revolution of the bullwheel. This is because the oscillating motion of the pawl carrier moves the pawl *forward* to push the ratchet wheel, and then *back* over one or more teeth, depending on the amount of feed for which the machine is set.

[1] *Pawl.*—A hinged or pivoted piece, or a piece arranged in a pivoted carrier (pawl carrier), having an edge made to engage with the teeth of a notched wheel (ratchet wheel) for the purpose of giving motion to, or receiving motion from, this wheel in a given direction.

The oscillating motion of the pawl carrier is given to it either (1) from a crankpin arranged to make one cycle when the bull wheel revolves once (Fig. 83), (2) from an eccentric on the bull-wheel hub (Fig. 84) which, of course, completes one motion when the bull wheel revolves once, and (3) in the more recent designs, from a cam on the end of the bull-wheel hub. This last mechanism, somewhat more involved than the others, is diagrammed in Fig. 87.

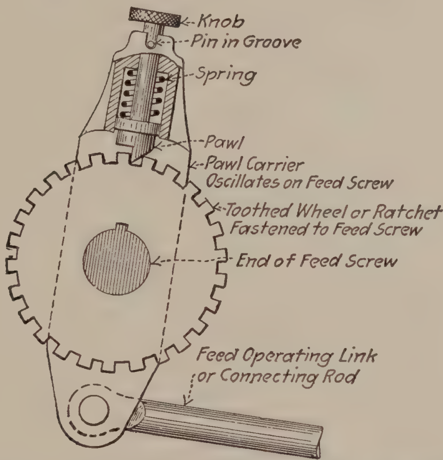


FIG. 82.—Illustrates one type of ratchet-and-pawl mechanism. The pawl carrier is *free* on the screw (not keyed), and when the carrier moves the pawl forward it moves the ratchet wheel which is keyed to the feed screw, and thus moves the screw a slight amount for the feed.

It is important to understand these ratchet-and-pawl feeding devices, and it should not prove difficult. The object of any such device is merely to make the ratchet wheel move. This is done by means of the pawl carrier rocking on its center, thus moving the pawl and pushing the wheel. To do this, the *circular* motion of the bull wheel is converted to *reciprocating* motion (feed-operating link), to a *rocker* motion (pawl carrier), and through the pawl back to circular motion (slow turning of ratchet wheel). This may be done by means of a crankpin (Fig. 83), or an eccentric and eccentric strap (Fig. 84), or a cam and roll (Fig. 87). Be sure to study the legends under

the illustrations. Remember, every mechanism well under-stood makes easier the understanding of the next.

The feed of the shaper should always take place on the return stroke because to feed during the cut puts undue strain on the feeding mechanism. If the feed motion is transmitted through a *feed rocker arm*, as is the case when actuated by an eccentric on the bull wheel (Fig. 84), then the position of the feed-adjusting knob, one side or the other of the rocker-arm center, determines whether the feed shall be during the forward or return stroke.

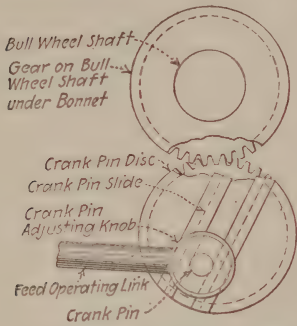


Fig. 83.—Shaper feed mechanism (operated by gears). The upper gear is fastened to the hub of the bull wheel and the lower gear is carried on a stud shaft in a bonnet. The crankpin disk is located in front of the lower gear. The gears are equal, therefore each revolution of the bull wheel causes an oscillating movement of the feed-operating link.

This same principle applies in shapers that have the feed-operating link or connecting rod actuated by a *crankpin* in a slotted disk, the disk being revolved by means of gearing at the outer end of the bull-wheel hub (see Fig. 83). A feature of the newer design, operated by a cam (Fig. 87), is the fact that the feed *always operates on the return stroke*. Bevel gears are used for reversing the *direction* of feed.

The amount of automatic feed is governed by the number of teeth the ratchet wheel moves at each return stroke of the shaper and this is controlled by the position, more or less off center, of the feed-link adjusting knob in the feed rocker arm (Fig. 84), or in the crankpin slide (Fig. 83), or by the amount the cam moves the pawl carrier through some such mechanism as shown in Fig. 87.

Some shapers have two pawls on one pawl carrier ("double pawl") with one pawl set half a tooth ahead of the other. This allows one half a tooth adjustment, that is, one-half-tooth feed.

79. Cam-operated Feed Action.—The shaper illustrated in Fig. 75 has the cam-operated feeding mechanism, and the

principle is diagrammed and described in Fig. 87. First, however, attention is called to a brief description of the pawl and

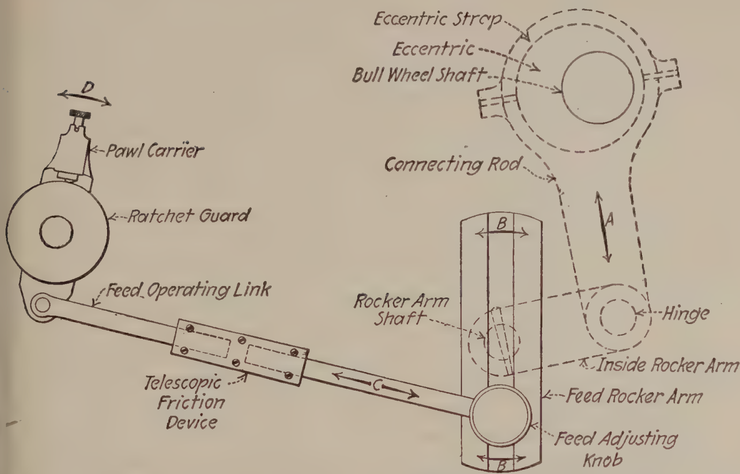


FIG. 84.—Shaper feed mechanism (operated by eccentric). The eccentric, connecting rod, and inside rocker arm are within the column. The revolving eccentric causes an up-and-down motion of the connecting rod (arrow *A*) which in turn causes an oscillating motion of the feed rocker arm (arrow *B*), also of the feed-operating link (arrow *C*), and of the pawl carrier (arrow *D*).

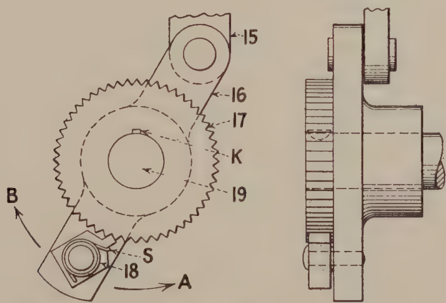


FIG. 85.—Pawl carrier (16); ratchet wheel (17); pawl (18). The key *K* keys ratchet wheel to feed screw (19). Pawl carrier is free—not keyed.

ratchet (Fig. 85) and the feed rocker and block (Fig. 86). (In Figs. 85, 86, and 87, like parts have corresponding numbers.)

Pawl and Ratchet.—As will be seen by reference to Fig. 85, the action of the pawl and ratchet is not unlike that shown in

Fig. 82. It will be noted, however, that the teeth are V-shaped instead of square, and that the pawl cannot be reversed (no need of it with bevel-gear reverse).

The ratchet wheel (17) is keyed to the ratchet shaft (19), but the pawl carrier (16) is free (no key) and may have more or less rocking motion, depending on the amount of feed desired. On the lower end of the pawl carrier is the pawl (18), held freely by the stud. A spring *S* is provided to keep the pawl in place during the feed, but to permit it to ride over the ratchet the given number of teeth for the next feeding motion. As will be observed, one direction of the rocking motion of the pawl carrier (arrow *A*) moves the ratchet wheel and its shaft, the reverse motion (arrow *B*) rides the pawl over the one or more teeth ready for the next feed.

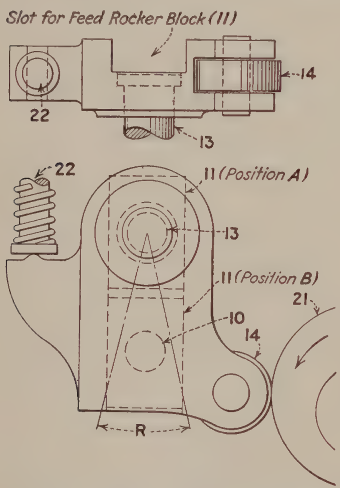


FIG. 86.—Feed rocker rocks on stud (13) through the arc *R* and carries in the slot the block (11) which in position *B* has maximum swinging movement.

Feed Rocker and Block.—Referring to Fig. 86, the amount the pawl carrier is moved and the consequent amount of feed are governed by the position of the *feed-rocker block* (11) which is adjustable along a slot in the *feed rocker*. The feed rocker is pivoted on a stud (13) which is fastened in the column of the shaper. A rocking (pendulum-like or swinging) motion is given to the rocker by the *cam* (21) on the end of the bull-wheel hub. The cam roller (14) is held against the cam by the spring plunger (22). When the block (11) is on center (position *A*) it merely *pivots* with the rocker, but when it is adjusted off center, it *swings* with the rocker. The extreme is shown in position *B*. The block carries a stud (10), and the motion—back and forth—of the

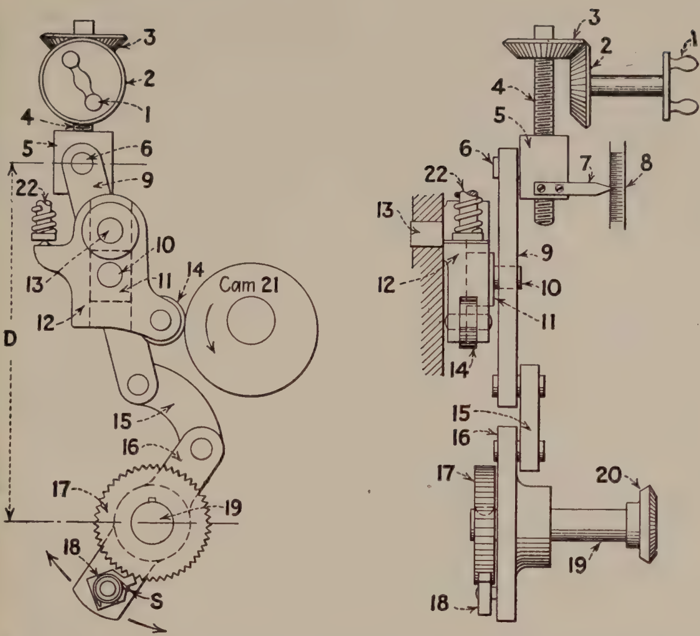


FIG. 87.—Shaper feed mechanism (operated by a cam). The feed handle (1) controls the amount of feed. Turning (1) turns the bevel gears (2) and (3) and the screw (4). The screw (4) threads into trunnion block (5) and adjusts it vertically. The block (5) carries the stud (6), the feed arm (9), the stud (10), and the block (11). Therefore, adjusting (5) serves to move the feed-rocker block (11) towards or away from the *pivot center* of the feed rocker (12) and thus changes the amount of feed as explained in paragraph 79. The pointer (7) on graduations (8) shows the amount of feed in thousandths of an inch.

The distance *D* between the stud (6) and the ratchet-wheel shaft (19) is changed when the block (5) is adjusted, and therefore the link (15) is provided.

In operation, the revolving cam (21), always in contact with the cam roller (14), causes a swinging or rocking motion of the feed rocker (12) on its fixed stud (13). This causes more or less of a swing of the feed arm (9) depending upon how much the center of the feed-rocker block (11) has been moved below the center of the rocker stud. The more swing the arm (9) has, the greater the movement of the link (15), the pawl carrier (16), and the pawl (18), and, consequently, the greater the number of teeth traversed on the ratchet wheel (17) and the greater the feed. To keep the cam roller against the cam, the spring (22) is prvided.

block is transmitted to a *feed arm* and *link* and thence to the *pawl carrier*. Thus for setting the amount of feed, the feed-rocker block is moved to any desired position between A (no feed) and B (maximum feed).

If the student understands the action of the pawl and ratchet (Fig. 85) and the swinging movement of the feed rocker block as just explained, he will be better able quickly to understand the whole mechanism, as illustrated in Fig. 87. It is the study

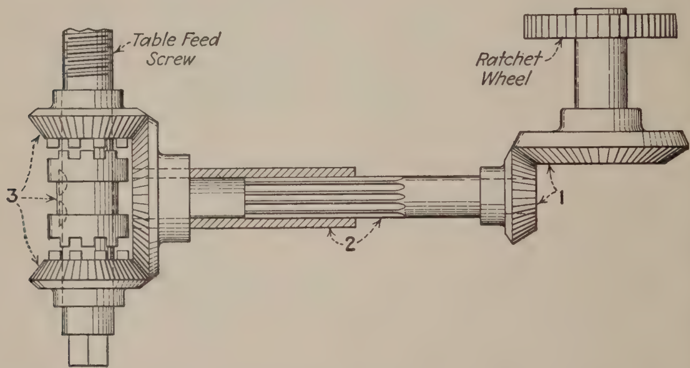


FIG. 88.—Shows how motion of the ratchet wheel is transmitted to the table feed-screw through bevel gears (1), telescopic shaft (2), *bevel-reversing gears* and clutch (3). The clutch, shown here in neutral position, is operated by lever (13), Fig. 75.

of mechanisms such as these that gives the mechanical insight that is so necessary for a machinist to have.

Bevel-gear Reverse.—To change the direction of the feed in shapers with the cam-operated pawl and ratchet, the bevel-gear reverse (Fig. 88) is used. (Another application of this reversing mechanism is shown on page 205.)

80. Toolhead. Vertical and Angular Downfeed.—The toolhead (Fig. 89) is designed to hold the tool and also for the purpose of adjusting the tool for the desired cut. A graduated collar on the downfeed screw serves to indicate the movement of the slide (and tool) in thousandths of an inch. Moreover, the slide and screw permit of a considerable downfeed and, because of the swivel construction between the head and ram, this feed may be vertical or at any desired angle in the

plane of the swivel. That is, a vertical cut of considerable depth or a fairly wide bevel cut may be taken in the shaper by means of the downfeed. The swivel headplate is graduated in degrees, and is easily adjusted after loosening the binding bolts.

The cutting tool is held in the tool post securely against the tool block or "clapper block." The tool block fits snugly

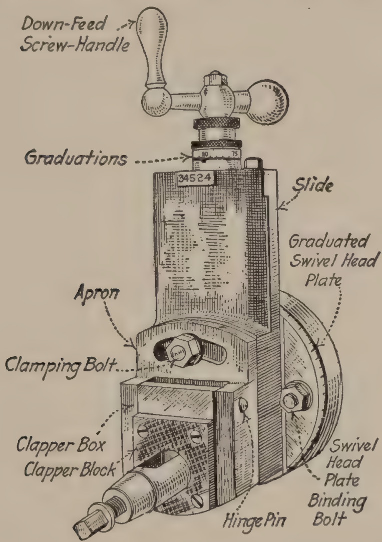


FIG. 89.—Shaper toolhead. (In the shaper shown in Fig. 75, the swivel head-plate binding bolt is number 23.)

to the sides and back of the clapper box and is held by the hinge pin.

During the cutting stroke the tool block is rigidly supported in the clapper box, but on the return stroke the block hinges outward slightly on the hinge pin allowing the tool practically to clear the work, and prevents the severe rubbing and consequent ruin of the cutting edge of the tool which would otherwise happen.

By loosening the apron[1] clamping bolt the whole apron may be swiveled through a small arc in either direction, for the

[1] *Apron.*—The tool block, clapper box, and hinge pin comprise what is called the "apron."

purpose of allowing the tool to clear the work when taking a vertical or angular cut. This is more fully explained in paragraph 105, page 120.

The power downfeed is a comparatively recent development in shaper construction but most manufacturers will now furnish this feature at the option of the purchaser. It is worth while for the reason that power feed is usually more efficient than hand feed.

NOTE: A definition of a gib is given on page 135. In the shaper, gibs are provided for three purposes—to adjust the saddle on the crossrail, to adjust the ram on the column, and to adjust the toolhead slide on the swivel headplate. The proper adjustment of these gibs is important, and the proper oiling of the bearings is imperative.

Questions on Shaper Construction II

1. What is an eccentric?

2. Describe the feed rocker arm?

3. In what direction does the rocker arm move on the forward stroke of the shaper? On the return stroke?

4. How is motion transmitted from the rocker arm to the pawl?

5. Describe the operation of a ratchet and pawl.

6. If the feed screw is $\frac{1}{5}$ pitch (5 threads per inch) every time it makes one revolution it moves the table $\frac{1}{5}$ in. If the notched wheel (ratchet) has 50 teeth, how much is one tooth of feed? Two teeth? Four teeth?

7. How is the amount of feed changed?

8. How is the power feed of a shaper reversed?

9. Have the feeds arranged to cause the table to move from right to left and note if the feed operates on the forward stroke or on the return stroke. Reverse the feed (to cut from left to right), does the feed operate on the same stroke as before?

10. What do you change to make the feed operate on the return stroke when the direction of the feed is reversed?

11. Why should the feed always operate on the return stroke?

12. How do you clean and oil the crossrail bearing surfaces?

13. How is the saddle-plate bearing adjusted on the crossrail? Why is the provision for adjustment made?

14. Examine the head of the shaper. How is the head fastened to the ram? How may it be swiveled?

15. Set the head over 30 deg. What angle will the downfeed make with a horizontal surface?

16. Set the head over to make an angle of 30 deg. between the downfeed and a horizontal surface. How much is the head swiveled?

17. What is meant by downfeed in a shaper?

18. How many thousandths does one revolution of the downfeed screw handle move the slide?

19. How many graduations are there on the graduated collar? If you move the handle one graduation, how far have you moved the slide?

20. What is the value of the graduated collar on the downfeed screw? Why is it adjustable?

21. Do you read the graduations or the figures, or both? Why?

22. Clamp a tool in the tool post. Is the tool firmly seated during the forward stroke? Can it lift slightly during the return stroke? Why is it so arranged?

23. Where does the hinge pin fit tightly? How does it fit in the clapper block? Where is it oiled?

CHAPTER V

SHAPER WORK

81. Shaper Cutting Tools.—The variety of cuts that may be made in a shaper on any of the metals used in machine construction calls for various shapes of tools. The general shapes are illustrated in the chart (Fig. 92). The similarity of certain of these tools to lathe tools will be apparent; they differ, however, in respect to the clearance angles. The

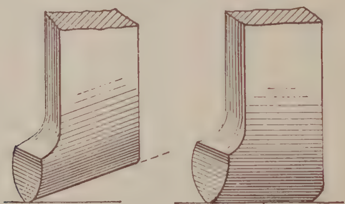


FIG. 90.—Front clearance on shaper tool: (*a*) too much; (*b*) not any, will rub; (*c*) correct, about 3 deg.

lathe turning tool, for example, is ground with 10 or 12 deg. front clearance, but is set above center to have the effect of perhaps 2 or 3 deg. working clearance.

82. Clearance Angles.—There is no rocker in the tool post of the shaper, hence the tool cannot be adjusted for clearance; the proper clearance angles must be ground on the tool. The front clearance angle is usually about 3 deg. (*c*, Fig. 90). Since the shaper feed does not operate during the cut as does the lathe feed, a side clearance of 2 or 3 deg. is plenty.

NOTE: The elements of a shaper tool or planer tool, that is, the front, side, front clearance, side clearance, front rake, side rake, etc., are in the same relative positions as on a lathe tool, regardless of the fact that the shaper tool when in operation is held vertically and the lathe tool horizontally.

If a shaper tool is given too much front clearance (*a*, Fig. 90), it will dull quickly because the cutting edge, not being backed up by metal, crumbles away; if given no front clearance, the cutting edge cannot well get under the chip and will merely rub, spoiling the appearance of the work. The same is true with regard to side clearance. Briefly stated, the shaper cut is a straightaway cut and just sufficient front and side clearance are given the cutting edge of the tool that there is no tendency for any part of the tool to rub.

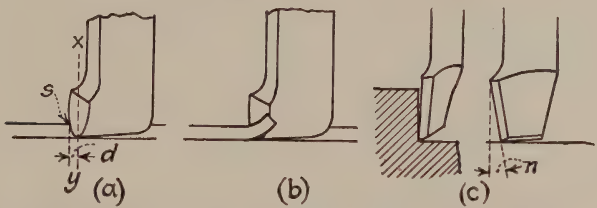


FIG. 91.—Cutting action of tool when machining a plane surface. Note in view (*a*) that line *xy* is parallel to the base of the tool and therefore the tool has no front rake. Note also that since the cutting edge is given side rake, the start of the cut is made at *s* and the distance *d* is traversed before the full depth of the cut is taken; thus the tool enters the work gradually and prevents the shock of the full cutting edge striking the metal at once. The way in which the chip curves is shown in (*b*). In (*c*) is shown a side tool with the cutting edge ground flat to take a finishing cut, say a quarter of an inch or more wide. Note the angle of shear *n* to give an easy start and finish of the cut. A side tool ground in this way is much used in shaper and planer work for finishing cast iron.

83. Rake Angle.—The shaper tool is usually given side rake of 10 deg. or more, depending on the kind of tool and on the hardness of the metal to be machined, but no front rake except in the finishing tools. The action of a tool when machining a plane surface is illustrated in Fig. 91.

84. Right-hand and Left-hand Tools.—When setting up a job in any machine, it is best if possible to arrange the work and also the tool in such a way that the operator can readily see the cut from his normal position at the machine, that is, from the position in which he controls the machine. For this reason it is customary when taking a horizontal cut on the shaper or planer to start the cut on the side toward the operator, and when shoulder or similar cuts are to be made,

to arrange the work so these cuts will come on this side. Many shaper jobs, however, include tongues, grooves, and angles which involve cuts on both sides of the work. Since in work of this kind it often makes for greater accuracy and

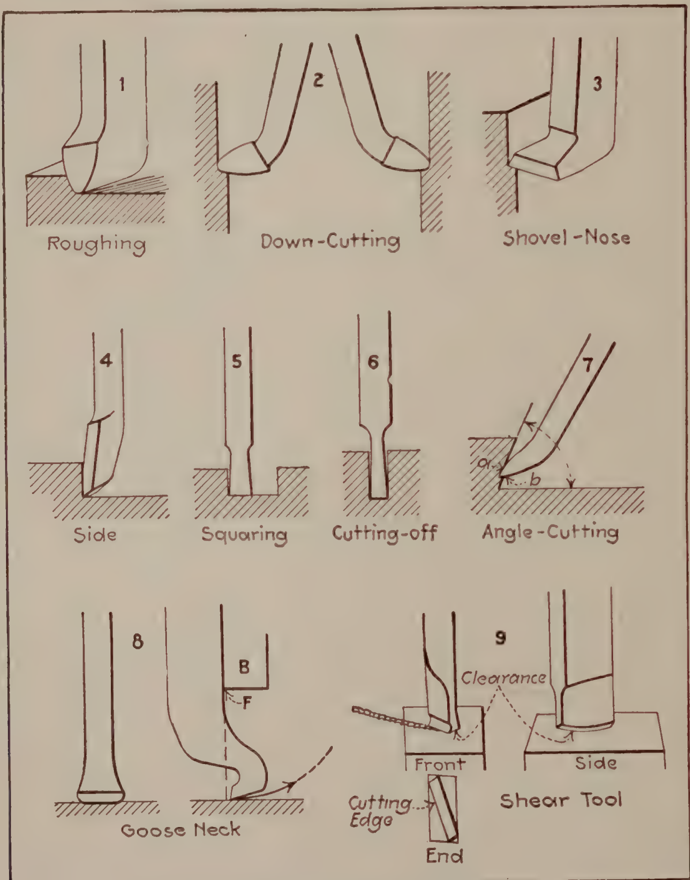


FIG. 92.—Chart of forged shaper tools.

speed to *machine in one setting of the work all of the surfaces possible,* it is necessary to have right-hand and left-hand tools. The terms right-hand and left-hand as applied to shaper or planer tools are derived from lathe tools of similar shape.

FORGED SHAPER TOOLS

1. *Roughing or "Shaper Tool."*—Similar in contour to lathe turning tool (Taylor). Has side rake but no top rake; amount of side rake, 10 to 20 deg., depends on the hardness of the metal being cut, the harder the metal the less the rake. For run-of-shop jobs a very efficient tool for roughing either cast iron or steel. To save the time of changing tools it may be used with a fairly fine feed for finishing smaller surfaces. Used mostly to cut to the left (as shown), but may be ground with the proper clearance and rake and used to cut to the right.

2. *Downcutting.*—Made substantially in the shape of right-hand or left-hand roughing tool except that it is bent as shown in order to cut down on a vertical surface.

3. *Shovel Nose.*—A very popular and efficient tool for cutting down; cutting edge is widest part of tool; corners are slightly rounded for longer life; cuts down equally well on either right or left side. A tool of this same general shape may be used with a very light chip, coarse feed, and a slow speed for finishing horizontal cast-iron surfaces.

4. *Side Tool.*—Made either right-hand or left-hand. Used for finishing vertical cuts and occasionally for finishing a narrow horizontal cut adjacent to the vertical cut.

5. *Squaring.*—Cutting edge is widest part of blade. Made in any desired width for roughing and finishing sides and bottoms of grooves, keyways, and shallow shoulder cuts.

6. *Cutting Off.*—Similar to lathe cutting-off tool, except for front clearance.

7. *Angle Cutting.*—Made either right-hand or left-hand. Cutting edges *a* and *b* are ground to the angle required, as for example, 60 deg., as shown. The cutting edge *a* finishes the angular surface, and *b* finishes the horizontal surface. A light cut and fine feed are used for finishing. For roughing, the point should be well rounded to give longer life to the tool.

8. *Spring Tool or "Gooseneck."*—For finishing cast iron. Owing to the fact that the cutting edge is back of the fulcrum point *F* of the tool shank in clapper block *B*, any spring of the cutting tool is in the direction of the arrow or away from the surface of the work. With this tool there is less tendency to chatter and to "dig in" than with such a tool as the shovel nose.

9. *Shear Tool.*—Used to obtain a particularly high machine finish on steel. It is forged with the blade about $\frac{3}{16}$ in. thick and twisted 15 or 20 deg. The cutting edge is ground on a curve (3- or 4-in. radius) and backed off. With 0.003 or 0.004 in. depth and one-tooth feed an excellent finish is obtained, especially if lard oil is used as a lubricant.

85. Toolholders.—The toolholder and high-speed-steel bit have largely superseded the forged tool for shaper work. The tool bit may be ground to the shape required to accomplish the desired result for practically any operation. Figure 93 shows a patented toolholder (Armstrong) which in the smaller size is used for shaper work and in the larger size is very efficient for use in the planer. The construction of this toolholder permits of the tool bit's being securely and rigidly held in any one of the five positions shown in *b* so that horizontal, vertical, or angular cuts either right-hand or left-hand may

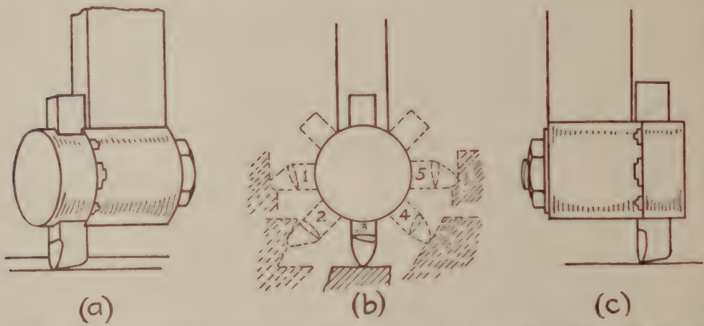


FIG. 93.—Armstrong planer or shaper tool. (*a*) Normal position for horizontal surface; (*b*) tool arranged for (1) vertical cut; (2) angular cut (inside angle); (3) horizontal cut; (4) angular cut; (5) vertical cut; (*c*) toolholder (and tool bit) reversed, brings cutting edge back of shank of toolholder.

be made. Another advantage of this toolholder lies in the fact that for heavy cuts the toolholder may be reversed in the tool post (and, of course, the tool bit is also reversed, *c*, Fig. 93). Since the cutting edge is then back of the shank of the tool, the tendency of the tool to chatter or to "dig in" is eliminated. In any case the tool bit should not be allowed to project too far, as this will result in unnecessary spring.

The lathe-turning toolholder and bit make a very satisfactory shaper tool provided the tool bit is not given too much clearance, especially too much front clearance. Of course, the position of the bit set at an angle of 20 deg. with the shank of the tool gives a front rake which, while not being desirable, is not prohibitive for light cuts.

The spring toolholder, an example of which is illustrated in Fig. 94, is especially useful in shaper work. Since the body is in the form of a substantial U-shaped spring, this toolholder provides the characteristic feature of the gooseneck (8, Fig. 92). A forming tool of the desired outline may be quickly made for use in this holder to produce a narrow irregular surface (see paragraph 110, page 127).

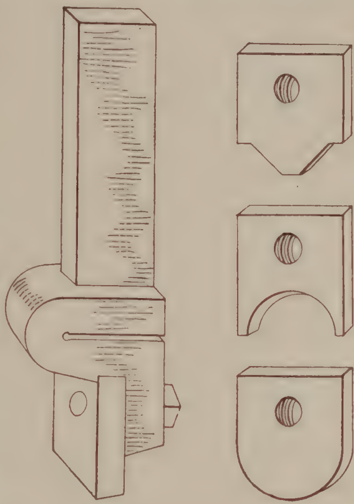


FIG. 94.—(*a*) Spring toolholder and square-nose tool. (*b*) Types of tools.

Questions on Shaper Tools

1. What is the general shape (contour) of the cutting edge of the most commonly used shaper tool?

2. How much front clearance has a shaper tool? How much side clearance? Why is a rocker not provided with the shaper tool post?

3. Why will a shaper tool dull quickly if given too much clearance?

4. Why is rake ground on a tool? Do the same principles that determine the amount of rake that is given a lathe tool apply to the shaper tool?

5. If a shaper tool has side rake, will it cut equally well if fed in either direction? Give reason.

6. What is the particular value of the spring tool?

7. How much rake has a shear tool? Are you able to grind a shear tool on the end of a tool bit?

8. Why is a shovel, nose tool particularly good for cutting down? Does it have value for radial facing in a lathe for the same reason?

9. Why is it wise to remove the tool bit from the holder before grinding?

86. Speeds and Feeds.—The reason for machining metal parts (in any machine tool) is usually twofold: (1) to remove surplus metal bringing the work to a given size, and (2) to produce a smooth surface. To accomplish these results, at least two cuts, one or more roughing cuts and a finishing cut, are nearly always necessary. To operate the machine efficiently to produce these results means a reasonable under-

standing of the proper speed, feed and depth of cut for roughing and also for finishing.

To understand the cutting speed is comparatively easy; it depends almost entirely on three things: (1) the kind of material being cut is a factor, the softer the material the faster the speed at which it may be cut. (2) The amount of material being removed in a given time is a factor, a light cut may usually be taken at a greater speed than a heavy cut; for example, the speed for a finishing cut in steel may often be increased 25 per cent over the roughing speed. (3) The kind of steel from which the cutting tool is made is a very important consideration because a high-speed tool will cut at least double the speed of the carbon-steel tool.

87. Depth of Cut and Feed.—The value of any machine tool depends upon its power; the strength and rigidity of its construction; the rapidity and smoothness of its action; its convenience in operation and its accuracy. Modern shapers may be classed as particularly rugged machines, carefully designed and accurately built. Whenever a considerable amount of metal must be removed, the shaper should be made to *work* during the roughing cut, that is, the cutting speed should be suitable and the depth of cut and feed should be proportioned to remove as big a chip as the shaper will drive, provided the nature of the work, the way it is held, and the strength of the tool will permit. It is impossible to give a rule for the depth of cut or the amount of feed, or for a proportion of feed and cut, but the following suggestions may help the beginner.

First, with a given tool and the given amount of metal to be removed per cut, a real coarse feed and less depth are not as efficient as a finer feed and a deeper cut, for two reasons: (1) the thick chip does not curl so easily and takes more power, and (2) the tear in the metal is greater thus producing a rougher surface. A safe rule to follow is to give as much feed as is consistent with the surface desired, and then all the depth of cut the machine and tool will stand, provided that amount of metal must be removed.

Second, the angle the cutting edge of the tool makes with the surface being cut has a considerable influence on the thickness of the chip. This is illustrated in *a*, Fig. 95, which represents three chips with the same depth *D* and the same feed *F* but different thicknesses *T* owing to the different angles the cutting edge *E* has with the surface of the work. It has been found by experience that a tool with the cutting edge about 20 deg. from the perpendicular *b*, Fig. 95, with the end well rounded, will give the most efficient results in roughing either cast iron or steel.

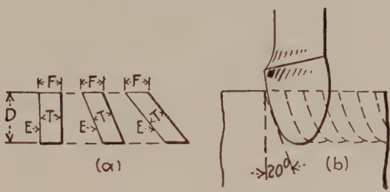


Fig. 95.

The following table of (average) cutting speeds and feeds of cutting tools made of carbon and high-speed steels is given for the convenience of the beginner.

Table of Speeds and Feeds

Cutting tool	Cast iron		Machine steel		Carbon steel		Brass	
	Speed	Feed	Speed	Feed	Speed	Feed	Speed	Feed
High-speed steel..	60	1/12	80	1/16	50	1/20	160	1/20
Carbon steel......	30	1/16	40	1/20	25	1/25	100	1/20

The usual practice is to run the shaper too slowly. It is well for the beginner to calculate the number of strokes necessary to give the proper cutting speed for the work at hand until he gets accustomed to seeing the shaper move fast enough.

88. Cutting-speed Calculation.—The calculations for cutting speed for shaper work are more involved than for lathe or drill-press work for the reason that the shaper cuts only

during the forward stroke, and further, the return stroke is faster than the cutting stroke.

Given the ratio of return-stroke *time* to cutting-stroke *time* (as explained in paragraph 75) as 2:3, the sum of the terms of the ratio equals 5; and $\frac{2}{5}$ of the time equals the *time* of the return stroke; and $\frac{3}{5}$ of the time equals the *time* of the cutting stroke.

Given the length of stroke in inches and the number of strokes per minute, their product gives the number of inches cut during one minute of the machine's operation. Since cutting speed is expressed in feet, this must be multiplied by $\frac{1}{12}$ to reduce to inches. As noted above, the actual time of cutting this distance is $\frac{3}{5}$ min. Therefore, since distance divided by time equals rate, divide the distance (in feet) by $\frac{3}{5}$ (that is, multiply by $\frac{5}{3}$) and the result will be the cutting speed. Instead of multiplying in every problem first by $\frac{1}{12}$ and then by $\frac{5}{3}$, it will be quicker to multiply by 0.14 which amounts to the same thing ($\frac{1}{12} \times \frac{5}{3} = 0.14$ approximately). Hence the following:

RULE I.—To obtain cutting speed, *number of cutting strokes* and *length of stroke* being given:

Multiply the number of strokes per minute (N) by the length of stroke in inches (L) and the product by 0.14.

Formula.—$0.14NL = CS$

Example.—Length of stroke 8 in. Number of strokes per minute 30. What is the cutting speed?

Solution.—$8 \times 30 \times 0.14 = 33.6$.

RULE II.—To obtain the number of strokes necessary, required cutting speed and length of stroke being given:

Multiply the cutting speed by 7 and divide by the length of the stroke in inches.

Formula: $N = \dfrac{CS \times 7}{L}$

(*Derivation.*—From Rule I, $0.14\ NL = \text{CS}$, or $N = \dfrac{CS}{L \times 0.14} = \dfrac{CS}{L} \times \dfrac{1}{0.14} = \dfrac{CS \times 7.2}{L}$ and for practical purposes $N = \dfrac{CS \times 7}{L}$ is near enough.)

Example.—How many strokes are required to plane cast iron with a high-speed tool (60 ft. per min.), with a stroke of 5 in.

Solution.—$\frac{60 \times 7}{5} = 84$ strokes.

Questions on Speed, Feed and Depth of Cut

1. The proper cutting speed for a given job depends on three factors. What are they? Give an example of each.

2. What is a safe proposition to follow concerning the feed and depth?

3. How would you grind and set a tool for roughing cast iron? For roughing steel?

4. About what cutting speed will be practical to start with on cast iron? Is the tool you are to use carbon steel or high-speed steel?

5. May it possibly be wise before long to change to a faster speed? To a slower speed? Give reasons.

6. How many strokes per minute are necessary to give the required cutting speed?

7. Do you suppose a machinist would use a formula to calculate the number of strokes necessary? How would he go about it? Of what value is the formula to the beginner?

89. Holding the Work.—Most shaper work is held in a vise which is bolted to the top of the table. However, the vise may be removed and work which is too large or otherwise impracticable to hold in the vise may be bolted to the top or side of the table, or to an angle plate or any special plate or other holding device fastened on the table. The cuts in Figs. 96 to 99 show typical shaper setups.

90. The shaper vise is illustrated in *F*, Fig. 75. The body may be swiveled on the base plate to any angle desired, graduations in degrees showing the angular setting. This swivel feature is often useful for beveling ends, planing adjacent faces at other than 90 deg., etc., but most of the work is done with the vise jaws either parallel with or at right angles to the direction of the cut. The shaper vise is especially strong, the jaws are long and deep, and the adjustment is sufficient to take work of a considerable width. The jaws are often left soft, and then great care must be taken when clamping work to

FIG. 96.—Planing a dovetail slide bearing. Note the set over of the head, and also of the apron for the angular cut.

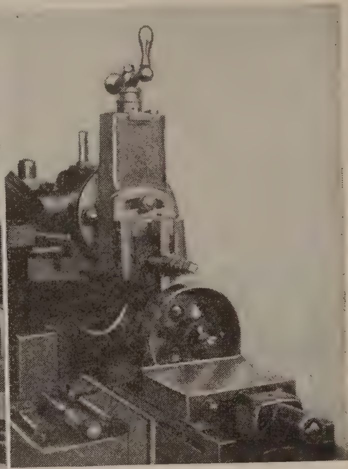


FIG. 97.—Planing a keyway in a pulley. (The pulley is held in a milling vise gripped in the shaper vise.)

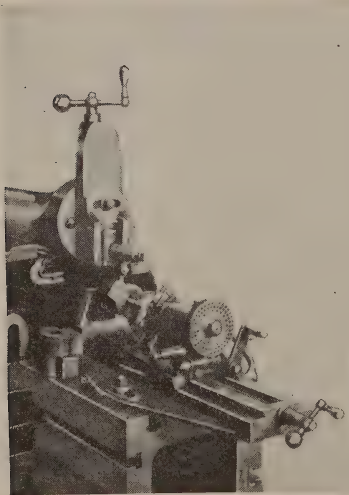


FIG. 98.—Using the shaper centers. Note the lug on the work that prohibits *turning* the circular portion as in a lathe.

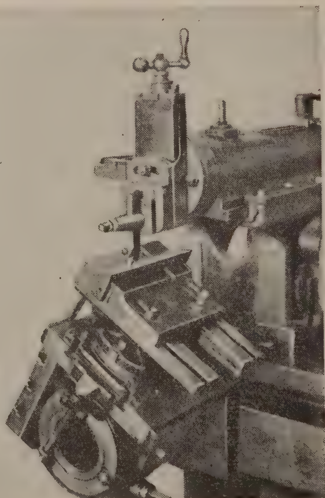


FIG. 99.—Shows universal table. In this manner the beveled surface may be planed with regular power feed.

prevent them from being scored and dented. An auxillary rocker jaw is furnished for securely holding tapered pieces.

91. Angle plates (Fig. 100) are of any size required, and are usually iron castings. An angle plate is composed of two

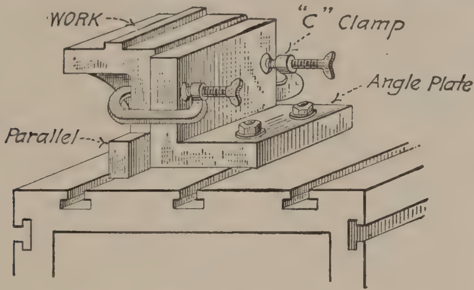


FIG. 100.—Work clamped to an angle plate.

members or wings, the outer surfaces of which are machined flat at an angle (usually 90 deg.) to each other. When in use, one surface is bolted to the table and the work is fastened to the other surface. Some angle plates have one of the inner

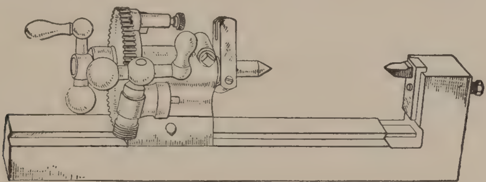


FIG. 101.—Shaper index centers. (*Courtesy of Potter and Johnson.*)

These index centers are designed to be gripped in the vise, and as the base of the vise is circular and graduated, the centers can be adjusted to any horizontal angle. The dead center has a vertical movement for taper work. The live spindle has screw adjustment longitudinally and it is revolved by worm and worm gear, or direct, with the worm thrown out of engagement. The worm gear has a series of holes drilled in its face, and the arrangement of the holes enables square, hexagonal, and other common forms to be planed. The adjustable index head has a longitudinal movement for the entire distance between centers. Swing, 4 in.; maximum distance between centers, 8½ in.

surfaces finished, which permits of work being bolted to this surface when desirable.

Holes are drilled where necessary for the clamping bolts, sometimes tapped holes are more convenient for the purpose of clamping the work, and often C clamps are used.

In an *adjustable angle plate* the two members are hinged and a device is provided for clamping them rigidly when they are set at the required angle to each other.

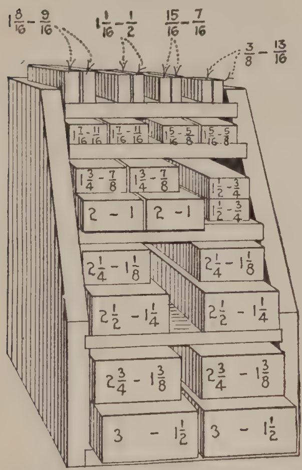


FIG. 102.—Parallels. (*Courtesy of O. S. Walker Company*).

92. Shaper centers (Figs. 98 and 101) are very useful for certain curved surfaces that are partially cylindrical but have projecting portions and consequently cannot be turned in a lathe. They may often be used for finishing surfaces of pieces held on a mandrel more advantageously than the work could be done in a milling machine. The construction of the head permits of a variety of indexing[1] operations.

93. Parallels (Fig. 102) are pieces of cast iron or steel of rectangular cross section, of considerable length in proportion to their width and thickness, with opposite sides parallel and adjacent sides square. They are used to raise the work to the

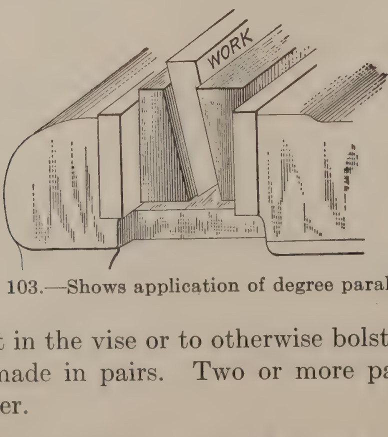


FIG. 103.—Shows application of degree parallels

required height in the vise or to otherwise bolster and level it. Parallels are made in pairs. Two or more pairs may often be used together.

[1] *Indexing.*—Turning the work an exact indicated amount on its axis.

94. Degree parallels (Fig. 103) so called, are similar to regular parallels except that one side of each parallel is planed "out of square" with the adjacent side a certain number of degrees.

95. Hold-downs or grippers (Fig. 104) are thin pieces of approximately triangular cross section, of the length desired, (6 in. more or less) used most frequently to hold thin pieces in the vise. The narrow edge is rounded and the opposite edge is beveled about 2 deg. toward the bottom. This insures the work being held down on the bottom of the vise or on a parallel as the case may be. Hold-downs are especially valuable when

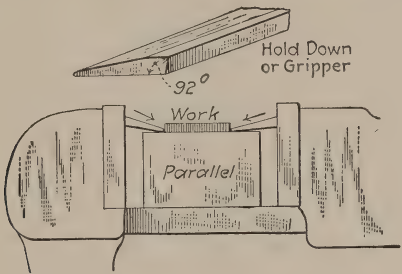


FIG. 104.—Shows action of hold-downs.

parallels of the required height to raise the thinner pieces just above the vise jaws are not available. They are very useful also when it is desired to finish only the two opposite surfaces of a piece.

CAUSES OF INACCURATE WORK

96. Inaccurate Vise or Vise Settings.—In most shops it may be assumed that the shaper vise, as it is arranged, is right enough for the average job, but it may so happen that it is necessary to plane in the shaper a piece which must be especially accurate—square, and to an exact size—in which case it will probably be advisable to test the bottom of the vise (on which the work rests) for parallelism, and also the solid jaw to make sure that it is square.

97. To Test the Work Seat.—Open the vise wide, be sure the bottom is clean and smooth and with an indicator of any

convenient kind (dial test indicator is perhaps best) try the work seat to make sure that it is parallel. If a pair of fairly good sized accurate parallels are at hand they may be arranged as shown in Fig. 105 and four places *A*, *B*, *C*, and *D* indicated for parallelism. If *B* and *D* are low, it will indicate that the worktable sags and probably the saddle gib will need tightening, or that there is dirt between the vise and the table. If either *A* and *B* or *C* and *D* are low, it will indicate no doubt that the vise is not properly seated on the worktable. These faults may be easily corrected to bring the work seat parallel.

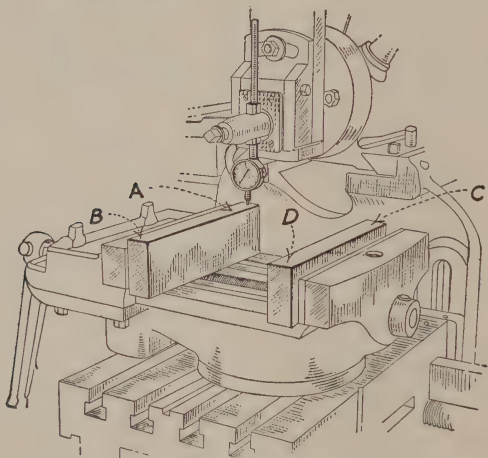


FIG. 105.—Testing the work seat for parallelism.

It may be advisable to shim with paper between the vise and the worktable.

98. To Test the Solid Jaw.—If the face of either of the jaws of the vise is dented and scored it should be repaired. If the solid jaw is not square with the seat it is impossible to clamp the work against the jaw and plane it square. To test for square takes only a few minutes. Clamp the beam of a square against the solid jaw (with a piece of wood between the movable jaw and the square), as shown in Fig. 106. Arrange the indicator and move the worktable the distance *A* to *B*. If the indicator registers the same at both ends of the

blade the jaw is square. It will be best to try the jaw near each end and in the middle. If necessary, shim the jaw until it is square.

99. To Set the Vise Parallel with Direction of Stroke.—While the graduations on the swivel plate are accurate enough for nearly all purposes, occasionally a cut, for example, a shoulder, must be made exactly parallel with the edge located against the jaw or the work may be spoiled. To test for this position is very simple. Arrange the length of stroke to

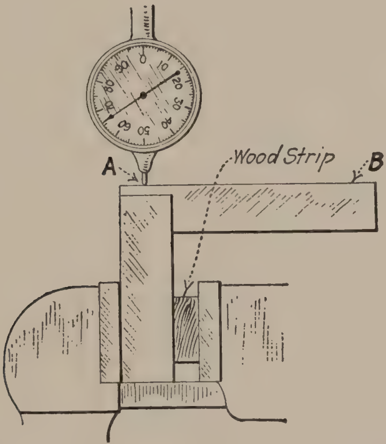


FIG. 106.—Testing the solid jaw for squareness.

about the length of the jaw, hold the indicator in the tool post and slowly run the shaper by hand to note if the indicator registers the same at both ends of the jaw. If necessary to make adjustment, clamp the vise lightly and tap with a babbitt hammer until the setting is correct, then clamp tight and test once more.

100. To Set the Vise Square with Direction of Stroke.—To test, and if necessary to correct the setting, the indicator is arranged as before, but, the vise being turned around 90 deg., the *worktable* instead of the *ram* is moved by hand to show the movement, if any, of the indicator needle.

NOTE.—An angle plate or similar holding device when clamped to the worktable may be tested for square or may be set square or parallel with the direction of the stroke in exactly the same way as the vise.

101. Chips and Burrs as a Cause of Inaccurate Work.—One of the most frequent causes of damaged or spoiled work is failure on the part of the operator before clamping the work to remove the burrs and clean the chips from the work and also from the holding device, whatever it is—vise, fixture, chuck, or clamp of any description.

Chips.—Steel chips are worse than cast iron chips, but if either are pinched between a finished surface of the work and the vise jaw, both the work and the jaw will be damaged, and possibly the work will be thrown out of true enough to ruin it. If chips are allowed to get under the parallels, or between the parallels and the work, it is obvious that the work will not seat properly and the finished surface cannot be accurate.

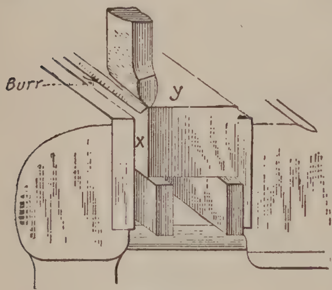


FIG. 107.

Burrs.—Particularly on steel and wrought metal the last few strokes tend to roll the metal over the corner forming a burr. This burr is more or less difficult to remove, depending a great deal on the sharpness of the shaper tool. If the surface x, Fig. 107, over which the burr is rolled, is the next surface to be machined, it will cause no trouble, but if surface x is to be used as a seat for finishing the opposite side, or if y is to be used as a seat, the burr must be removed. Sometimes the heavier burrs are removed with a special burring chisel similar to a wood chisel; the lighter burrs are easily removed with a fairly fine file. In either case be very careful not to spoil the corner.

Then there is another kind of burr, the kind thrown up by making a nick or dent in a piece of metal. For example, pinching a rough forging or casting between the soft vise jaws without using protecting pieces will dent the jaws and throw

up burrs; likewise, pinching a chip between the vise jaw and the finished surface. Dropping a parallel so it strikes the machine may nick it and throw up a burr, and hammering a rough piece down on the parallel will do the same.

It is certain that if the work itself, the holding device, and the parallels are not clean and otherwise in good condition, at least two evils will result: (1) the work will be inaccurate, damaged, and possibly spoiled, (2) the parallels, vise, etc., will be damaged.

102. Preliminary Hints on Shaper Work.—1. Keep the machine clean and well oiled.

2. Use the proper wrench or handle, and when not in use, keep them where they belong.

3. A vise jaw that is scored and dented and out of true is a disgrace in any shop. A real mechanic is careful. Use brass or copper or cardboard to protect the jaws when clamping the rough surfaces of bar stock, castings, or forgings.

4. Parallels should be kept clean, free from burrs, straight, parallel, and square. Examine them before using and be sure they are at least clean and free from burrs. Do not hammer a rough piece down on a parallel.

5. Be sure there are no chips on the seating surfaces, or the clamping surfaces of the vise, parallels, and work.

6. Carefully remove the burr caused by any previous cut if it will interfere with the proper seating or clamping of the work.

7. Select the proper tool, grind it carefully and oilstone it. A workman is often judged by the tools he uses.

8. To seat the work use a babbitt hammer or babbitt ball. Do *not* use a wrench.

9. Do not hammer the work with the babbitt, tap it just hard enough to seat it. Do not tighten the vise again after seating the work as this is likely to lift the work a trifle.

10. Tissue paper "feelers" between the parallels and the work are often very useful to determine if the work is properly seated.

11. Do not pinch a thin piece of work too tight or it will buckle more or less and be out of true when the pressure is released.

12. Be sure the top of the table and the bottom of the vise plate are clean and also free from burrs before resetting a vise that has been removed from the worktable.

13. When setting the tool to a surface already finished (or to a size block), be sure the tool block is firmly seated, place a piece of tissue paper under the cutting edge, and then feed the tool down to lightly pinch the paper.

14. When setting up irregular work, be sure the head and also the bottom of the ram will clear the work, during the whole length of stroke and the whole width of the cut.

15. Be sure, at all times, that the tool block works freely and seats properly. Failure to do this has caused a lot of spoiled work.

16. Do not hammer the side of the apron to swivel it. If the edge of the seating surface of the apron is dented and burred it will cause the tool block to bind in the box.

103. The Horizontal Cut.—When the work is fed in a horizontal direction under the reciprocating cutting tool, the surface produced is a horizontal flat (or plane) surface. Most of the work done in the shaper is of this description. The length of the stroke is set for approximately ¾ in. longer than the work and the position of stroke such that ½ in. of this extra length comes at the beginning of the cut to allow the tool block to seat properly for the next cut. If a given piece may be planed either crosswise with a short stroke or lengthwise with a longer stroke, other things being equal, it is better to take the longer stroke. To plane, for example, a piece 3 by 6 in. twice as much time will be wasted cutting air when cutting crosswise as when cutting lengthwise. This is illustrated in Fig. 108 where the shaded portion *B* shows air cut with cross stroke and *A* the air cut with the lengthwise stroke.

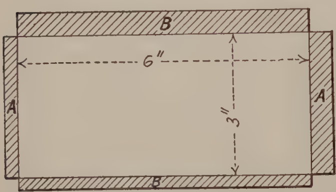


Fig. 108.

An important point in shaper construction and operation may be emphasized here. The shaper manufacturer takes the utmost care to have the clapper block fit the box. The bearing surfaces are scraped to provide the best of sliding fits with no shake, the axis of the hinge pin is exactly at right angles and consequently the block *hinges freely* in the box during the return stroke and is rigidly supported during the cutting stroke. The bearing surfaces should be wiped clean and a very little oil applied at least once a week. If the bearings are allowed to become dry or gummed with old oil or if for any other reason the block does not always seat properly trouble will surely result.

The position of the operator is at the right front of the machine with the speed and feed changes within easy reach. A low stool should be provided. In order that the depth of cut, the action of the tool, etc., can be more readily observed, the cut is usually started on the right side (the side nearest the operator), the feed of the table is arranged to move the work toward the operator *on the return stroke*, and the left-hand tool is used.

The smaller pieces or any pieces that will tend to tip under the pressure of the cut are best held with the vise jaws at right angles to the thrust.

There is practically no difference in roughing steel or cast iron except the cutting speed. For roughing plane surfaces of either cast iron or steel the tool illustrated in (1), Fig. 92, or a tool bit ground to a similar shape and held in a suitable holder may be used.

Clamp the tool in a vertical position or pointing *a very little* in a direction away from the work, so that if by any chance the tool moves owing to the pressure of the cut, it will move away from the surface instead of under cutting.

Do not allow the cutting edge to project too far from the tool post—"catch it short"—and clamp it tight. *Be sure the toolhead slide is not run down too far as this causes weakness and undue strain. It is much better to take time to raise the*

worktable than to allow the tool slide to project below the head or to have the tool project too far.

The tool is adjusted to take the depth of cut desired by means of the downfeed handle, and the work is fed by hand (cross feed) until the cut is started, then, *and not until then*, the power feed is thrown in.

When planing cast metals, the edge at the end of the cut should be beveled with a chisel or an old file about 45 deg., practically to the depth of the cut (see Fig. 109); otherwise chunks of the corner will break out below the surface leaving the edge ragged.

Cast-iron scale is hard and gritty. Set the tool to take a chip deep enough *to get under the scale.* If during the cut a portion of the surface is low and the tool rubs on the scale the cutting edge will very soon be ruined. Provided it will not make the work undersize, take a deep chip, and if necessary reduce the amount of feed, but *get the roughing cut under the scale* if possible.

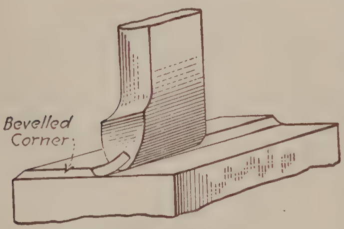


FIG. 109.

The finishing cuts should always be light. For finishing steel or wrought iron a fine feed will give the best result. A tool of substantially the same shape as the roughing tool but with a narrower rounded end and a greater rake angle produce an excellent finish, or if desired the shear tool shown in (9), Fig. 92, may be used.

The accepted commercial machine finish on flat cast-iron pieces of any considerable size is a surface that feels smooth and shows feed marks ⅜ in. or more apart. This finish is obtained by the scraping action of a broad square-nosed tool. This tool may be a forging, or the tool bit fitted to any one of a number of kinds of toolholders may be ground to shape. The best toolholder and tool for this purpose is probably a spring tool of a type illustrated in Fig. 94, page 103. It is usually better to use a spring tool so that any tendency of the

tool to "dig" will be overcome. With a sharp tool, 0.002- to 0.004-in. chip, and ⅜ in. or more feed, a beautiful finish may be obtained. Use a slow speed and feed by hand. If the surface left by the roughing tool is badly torn, it may be necessary to take two cuts.

When finishing cast iron, the edge at the beginning of the cut should be filed slightly bevel so that the cutting edge of the tool will not strike the scale. Keep oil off cast-iron work, even oily finger marks may defeat a good finish.

104. To Sharpen a Square-nose Tool for Finishing Cast Iron (Fig. 110).—Grind the front of the tool flat with 4 or 5 deg. clearance and round the corners slightly, oilstone the top and set in the tool post as nearly correct as can be judged (cutting edge flat on surface to be finished). Place a sheet of heavy paper on the work and on the paper a good oilstone. The paper is to keep oil off the work. Raise the tool block, that is, hinge it forward, and bring the oilstone and paper under the cutting edge of the tool. The tool block is now probably hinged forward 15 deg. or more; raise the slide until it only hinges forward a very little (about 3 deg.). Bearing lightly against the tool, rub the oilstone back and forth between the paper and the cutting edge. Lift the tool, that is, hinge it way forward occasionally and note when it is oilstoned enough, then remove the oilstone and paper, and allow the tool block to fall back into place. It is obvious that the tool is sharp, and that the cutting edge is parallel with the work and has the proper clearance (about 3 deg.). Feed down carefully to the work and take a very light chip, a coarse feed and a slow speed.

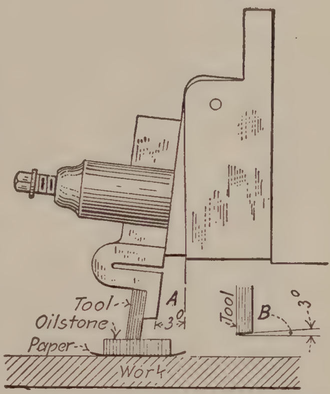


FIG. 110.—If the tool is oilstoned when hinged forward, say 3 deg., as at *A*, then, when it is seated, as during a cut, it will have 3-deg. clearance as shown at *B*.

105. Setting the Head for Vertical and Angular Cuts.—The downfeed is used for vertical cuts such as finishing the sides of tongues and grooves, squaring shoulders, squaring ends, cutting keyways, and occasionally for cutting off. It is used also for angular cuts such as fairly widebeveled edges and ends, and for dovetails.

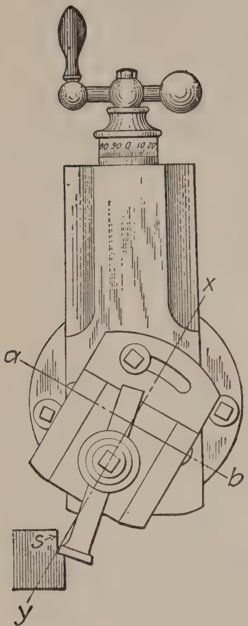


FIG. 111.—Apron swiveled for vertical cut. Axis of hinge pin is in line of *ab*. The direction in which the tool block may raise on the return stroke is in a plane *xy* at right angles to *ab*. If this plane is tipped away as illustrated, the tool will tend to raise in a direction away from the surface *s* and will not rub. If the plane is vertical the tool will rub along the surface *s* on the return stroke.

Except in the case of cutting off or a similar operation, or where the surface being planed is not much over ¼-in. deep (or high) it is very necessary to swivel the apron when using the downfeed. This is illustrated in Fig. 111. When the top of the apron is moved in a direction *away* from the surface of the cut, the tool block and tool will hinge in a direction up and *away from* the work during the return stroke. This is true in angular (bevel) cuts as well as vertical cuts (see Fig. 112).

The setup for an angular cut with the head swiveled and the apron also set over sometimes appears awkward and wrong. It may help the beginner to imagine the angular cut as a vertical cut and set the apron accordingly. For all vertical or angular cuts it is important to understand and remember the following:

RULE.—Always set the *top* of the apron in a direction *away from* the surface of the cut to be taken.

Although the construction permits of considerable downfeed of the head, it is not good practice to use the head with the slide run down much below the swivel plate because in this position it is not as strong and rigid as when backed up by the

ram. Sometimes it may be advisable or even necessary, but in no other case than for a finish cut.

Further, when the head is set over for an angular cut and the tool slide fed down too far, it is likely to bring up against the column as the ram slides back. Be careful, when setting up, to have the slide high enough at the start for either a vertical or an angular cut, that this weakness or this interference will not result during the cut.

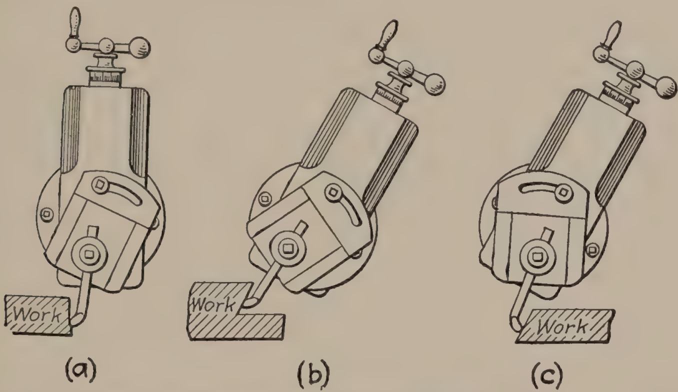


FIG. 112.—Note in each case the top of the apron is set over in a direction away from the surface being cut.

106. Planing Vertical or Angular Surfaces.—A *vertical cut* is made in the shaper (or planer) by setting the head exactly on zero, arranging the apron so that the tool will clear the work on the return stroke, and feeding down.

An *angular cut* is made by *swiveling the head* of the machine, arranging the apron so that the tool will clear the work on the return stroke, and feeding down.

It should be understood that it is not always necessary to take an angular cut to produce an angular surface. An *angular surface* is one that is neither parallel nor square to a given base or other surface. It may be machined in several ways:

a. The work may be supported on a tapered parallel (this is often called a taper cut).

b. A layout line indicating the position of the surface to be planed may be scribed on the work, and the work held in the vise with this line horizontal and the regular power feed used (for either taper or angle).

c. The work may be held in degree parallels (Fig. 103).

d. The vise may be swiveled to an angular setting.

e. Some shapers are provided with the universal table illustrated in Fig. 99.

f. The head of the shaper may be swiveled as shown in Figs. 96 and 112.

Except a downcut on a piece held in a vise which has been swiveled to a given angle [as in (*d*) above], all of the first five methods suggested require only the regular horizontal cut. The last method (*f*) involves the angular setting of the swivel head and is very properly called "an angular cut."

Attention is called to the setup of the shaper (or planer) for the downcut for producing either a vertical cut (*a*, Fig. 112) or an angular cut *b* or *c*, in the same figure.

Questions on Shaper Work, I

1. What precautions should be taken regarding the vise jaws? Why?

2. What are parallels used for? How should they be cared for? Why?

3. Is it good practice to pound rough castings or forgings or bar stock down on parallels? How should they be protected?

4. What are "hold-downs" or "grippers?" How are they used? When are they used?

5. State four ways in which the vise may be "out" enough to cause inaccurate work.

6. Explain how you may test the work seat.

7. Explain how you may test the solid jaw.

8. How do you set the vise jaw *exactly* at right angles with the direction of the cut? Exactly parallel?

9. Why is it necessary, in order to do good work, to keep the vise jaws clean?

10. What causes a burr on the work? There are times when it is unnecessary to remove this burr. Explain. If you have several pieces, when do you remove the burrs?

11. How much longer than the length of the cut do you set the length of the stroke? Why?

12. How is the tool arranged in the tool post for a horizontal cut? Why is it tipped? Why is it tipped "a very little"?

13. Frequently one sees the tool slide run down 2 or 3 in. below the head. What does this indicate? What is the remedy?

14. When taking a cut in cast iron, why should you, whenever possible, plane under the scale the first cut?

15. What is the proper way to take a finishing chip on cast iron?

16. Explain how to sharpen the square-nose tool for a shaper cut.

17. How does the clapper block fit the clapper box? Does it shake? Does it bind?

18. Are the bearing surfaces of the block and box smooth and clean? When and how should these surfaces be cleaned and oiled?

19. How may the apron be swiveled? How much?

20. Explain how hammering the side of the apron may prevent the proper seating of the tool block.

21. Clamp a short piece of board vertically in the vise allowing it to project a couple of inches above the jaws. Swivel the clapper box to the right and arrange to have the tool point touch the right-hand side of the board. Lift the tool. Does it clear the work? How much?

22. Arrange to have the tool point touch on the other side of the board without changing the position of the apron. Can you lift the tool? What happens. How will you arrange to have the tool clear the work?

23. If the board is tipped 30 deg. from the vertical and the shaper head is swiveled 30 deg. will the same principles apply (both sides of the board) as applied in the preceding questions?

24. Why is the clapper box made so it can be swiveled on the head?

25. What is the rule for setting the apron when taking a vertical cut or an angular cut? Why is this rule important?

26. Why, when cutting in two a fairly thick piece in a shaper, is it best to cut halfway through from one side and then turn the piece over and make a cut to meet the one already made?

107. To Plane a Rectangular Block or Similar Piece Square and Parallel.—Plane one side, preferably one of the larger surfaces (1) in Fig. 113, then using this surface as a seat against the solid jaw, plane the adjacent side (or edge) (2). If the shaper vise jaw is square and smooth and if the surface first finished is clean and free from burrs and properly seated against the vise jaw, the second surface planed will be square with the first surface. In order to make sure that the surface first planed is properly seated against the vise jaw, it is customary to use a rod or strip between the movable vise jaw and the

work. This will obviate any tendency for the work to change its position, owing to any "give" in the movable jaw.

Next place the second finished surface down on the bottom of the vise, or on parallels if necessary, and the first surface against the solid vise jaw as before, with the rod or strip between the movable jaw and the work, and tighten the vise. With a babbit hammer tap the work down in the vise to make sure that it is properly seated on the bottom, and plane surface (3). If the vise jaw is square and the tool is sharp and if care is taken to clean the surfaces of the finished work from burrs and chips, the two edges just planed should be parallel, and both square with the first side planed. Now place the

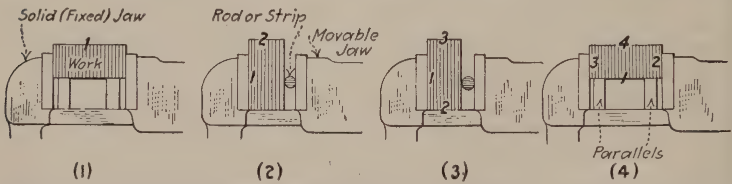


FIG. 113.—The four successive steps in planing the sides of a rectangular piece.

first planed surface down on suitable parallels, clamp the work between the jaws *without* the rod or strip, and with a babbitt hammer, tap (not pound) the work until it is properly seated. If the vise is true and the work is seated on both parallels so that neither parallel can be moved, then it is obvious that the fourth surface will be parallel with the first surface and square with the other two sides.

It is better to seat the work on two parallels rather than on one, for the reason that it is easier to judge if the work is properly seated. Further, it may be desirable to measure the piece with a micrometer or caliper; this may be more readily accomplished if there is a space between the two parallels or between one parallel and the vise jaw.

108. The Adjacent Surface.—If a piece of work having one side planed is to have either or both adjacent surfaces planed square with this side, the work must be set up properly. If for any reason the work is not "square in the vise," the

adjacent surface, when planed, will not be square with the surface already planed. If, for example, the solid jaw is "out of square" and the work tightened against the faulty surface, the work will be as much out of square as the vise jaw.

In paragraph 98, page 112, it was assumed that when the solid vise jaw is not square and true, time should be taken to

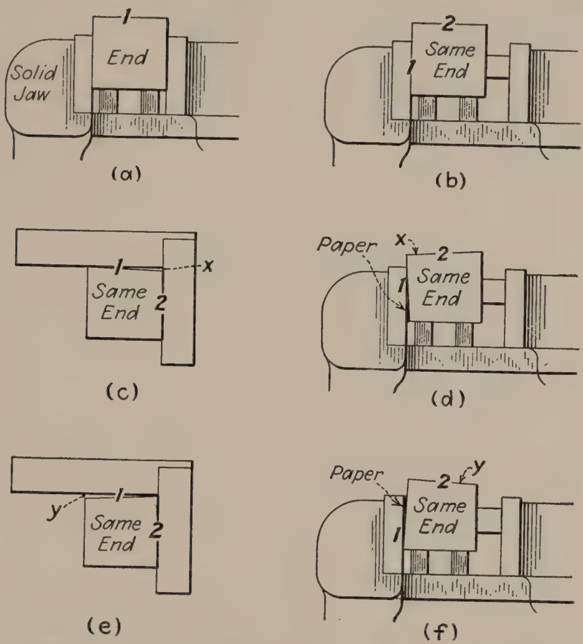


FIG. 114.—The use of a paper shim. Suppose the cuts 1 and 2 are made as in (*a*) and (*b*), and tested with a square; if more than 90 deg. (shows light at *x*) shim along bottom as in (*d*); if less than 90 deg. (shows light at *y*) shim along top as in (*f*).

correct the fault. This is not always possible; frequently it is advisable to shim the work in the vise rather than shim the vise jaw. This may be done, with paper usually, as shown in Fig. 114.

It is important to understand, further, that unless the *bottom* side is square with the side against the solid jaw, both of the parallels under the work will not be tight. This

is shown in an exaggerated manner in Fig. 115. No amount of hammering will "squash" the steel and seat the work on both parallels when the work itself is out of square or when it is held out of square, but a few taps with the babbitt will seat the work on both parallels when conditions are right.

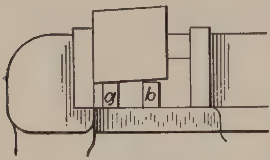


Fig. 115.

109. Squaring the Ends.—The ends may be planed square in two ways, the shorter pieces by taking the cut horizontally across, and the longer pieces by cutting vertically downward. The short piece is set in the vise, either on the bottom of the vise or on a suitable parallel, and a finished edge or side set perpendicular by means of a machinist's square as illustrated in Fig. 116. Hold the square down hard on the parallel and the piece of work hard against the blade of the square and tighten the vise lightly. Check the setting, tap the work one

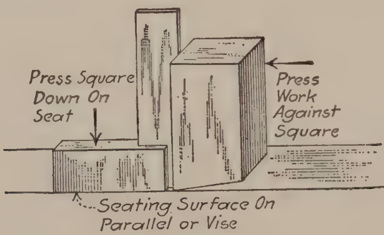


Fig. 116.

way or the other if necessary, then tighten securely. If this is properly done, and the vise jaws clean and square, the end when planed should be square with the surfaces already planed. To finish the other end it is merely necessary to seat the work on the finished end, tap carefully with a babbitt hammer to make sure that it is seated, and finish to the length required.

If the work is too long to finish the ends in this manner, it may be set lengthwise in the vise, letting one end project in a position to be finished by a vertical cut. Use parallels to raise it substantially flush with the tops of the jaws and allow it to project from the end only a short distance. A tool like

either (2) or (3) in Fig. 92 may be used in this operation. Tighten the vise securely. Run the tool slide well up toward the top, swivel the apron, and adjust the tool. For the reason that the tool will probably have to project some little distance from the tool post in order to take the cut to the bottom of the piece without interference, a feed and chip somewhat lighter than for horizontal planing will be advisable. Care must be taken not to break out the corners at the end of the cut if cast metal is being planed. An excellent finish may be obtained on cast iron with a side tool; have about ¼ in. of the cutting edge ground straight and set vertically; take

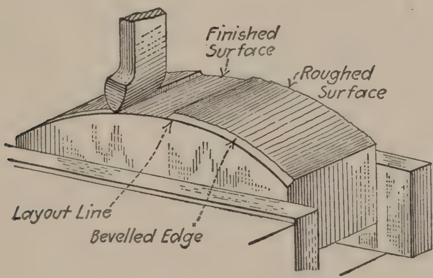


Fig. 117.

a very light chip, and a half turn of the downfeed screw for feed.

110. Planing an Irregular Cut.—A narrow irregular surface may be finished very efficiently with a forming tool. It will be better to hold the forming tool in some sort of a spring toolholder such, for example, as illustrated in Fig. 94. Even if only a few pieces are to be planed, it will probably be worth while to make a suitable forming tool. When planing a wider irregular cut, it usually is customary to lay out the irregular shape on the end of the work and plane to this line. When planing an irregular piece to such a line, it is a good plan to rough to within a $\frac{1}{16}$ or $\frac{1}{32}$ of the line and then with a file bevel the edge to the line at an angle of 45 deg. or more, as illustrated in Fig. 117. With a suitable tool, with a round nose if convenient to use, plane off the bevel. If the bevel

only is removed, then the surface is finished to the layout line. It is easier to see the bevel and gauge the cut than it is to split the line without the bevel. When planing a wide irregular cut of a curved outline, the vertical *hand feed* may be employed in connection with the *power table feed*. *It is easier and better to feed down than up;* therefore, start at the highest part, feed down by hand, and feed the table in the desired direction, either by hand or power, usually by power.

111. Planing Tongue and Groove.—In nearly all cases where such operations as tongues and grooves (Fig. 118) or dovetails

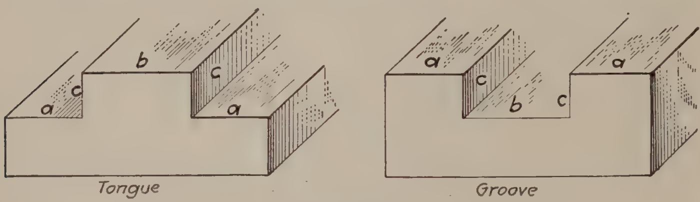


Fig. 118.

(Fig. 124) are to be made, a base surface is assumed to be planed. Also the surface where the tongue or groove or dovetail is to be cut is roughed to within $\frac{1}{32}$ in. The other surfaces are usually planed square with the base surface at the same time if they are ever to be planed. Assuming that these surfaces are already planed, proceed with the tongue or the groove, whichever is preferred. The tongue is considered easier because there is more room for the tool.

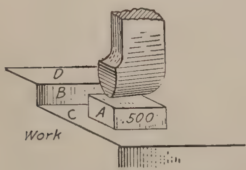


Fig. 119.—Use of size block. A, $\frac{1}{2}$-in. size block; B, shoulder; C, finished surface; D, surface to be finished $\frac{1}{2}$-in. from C.

When planing tongues and grooves or other shoulder operations, the roughing cuts should be made fairly close to the dimensions required, using the regular shaper tool with a small round nose whereever convenient. When finishing, the surfaces a and b (Fig. 118) are planed to the degree of accuracy desired, but on each of these surfaces there is usually left a thousandth or two for the fitter to file or scrape off. For the distance

from the surface *a* to surface *b* the graduations on the downfeed screw may be accurate enough, or if desired a size block (Fig. 119) may be used.[1] If the work is cast iron, the tool illustrated in (5), Fig. 92, may be used for finishing all of the surfaces *a*, *b*, and *c*. If the work is steel, the finishing tools for the corners (and also for the bottom surfaces) may be shaped like (1) and (2) in Fig. 120. The cutting edges for side and bottom are represented by *x* and *y*, respectively. These tools are given 15 or 20-deg. side rake.

Many machinists prefer to finish the smaller shoulder cuts in steel as well as in cast iron with a square-nosed tool without rake [(5) in Fig. 92]. This saves changing tools and is satisfactory for small jobs and light cuts.

112. The Horizontal Surfaces of Tongue and Groove.—To finish the horizontal surfaces, proceed as follows:

1. If the shoulder is under ½ in. high, use a square-nose tool and have the apron in normal (vertical) position. Be sure the tool is properly ground and set "square."

2. If the shoulder is over ½ in. high and the right- and left-hand shoulder tools are used, have the apron "set over" in the right direction and then set the tool square.

3. When using the graduations on the downfeed for gauging the vertical distance, first plane the top surface of the tongue (*b* in Fig. 118) to the finish size, then run the tool down the right distance and finish surface *a*, beginning at the edge and feeding toward the center. Both surfaces *a* may be finished with one setting of the tool.

4. When using a size block (Fig. 119) to gauge the vertical distance, first plane surfaces *a*, then set the tool by the size block, and finish surface *b*.

5. When shoulder tools are used it will, of course, be necessary to reset the apron and change the tool to plane the second surface *a*. In this case, set the second shoulder tool to touch

[1] A set of gauge blocks or "size blocks" is of great value to gauge the setting of the tool for shoulders or similar projections. Gauge blocks of any desired size, hardened, ground, and lapped for extreme accuracy, may be purchased, but for ordinary shaper work a piece of cold-rolled steel of the required thickness will answer.

tissue paper on the finished surface and plane the second surface exactly in line with the first.

113. The Vertical Surfaces.—1. When a vertical surface over ½ in. high is to be finished, it is usually necessary to set over the apron to allow the tool to clear the work; it is advisable to do this even when finishing the horizontal cut to a fairly high shoulder. (See paragraphs 105 and 106.)

2. For the smaller jobs, say a tongue not over ½ in. high, the square-nose tool (5) in Fig. 92, page 100, may be used for all surfaces (no setover of the apron is needed).

3. For the larger jobs the shoulder tools (Fig. 120) are best. Set over the apron according to the rule on page 120.

4. Whichever tool is used, first cut away (with this tool and hand feed) most of the fillet left by the round-nose tool when roughing. Then finish the vertical surface to the layout line, or to measure or gauge if advisable, and feed down to the horizontal line.

5. To finish the second vertical surface if the apron has been set over for the first, reverse the position of the apron and change the tool.

6. If the square-nose tool is used without setting over the apron, merely run the tool up and over to the beginning of the other vertical surface and plane down to make the tongue the correct size.

114. Planing the Groove.—Instructions for planing the groove are similar to the above for planing the tongue except for the roughing cut. To rough the groove proceed as follows:

With a cutting-off or similar tool, cut slots *inside* of the layout lines for the groove, one slot on each side nearly to the bottom of the groove. Then cut away the metal remaining between the slots, possibly with the tool just used if only a small amount of stock is left. This will leave the groove roughed out nearly to the layout lines.

When finishing the bottom of the groove with shoulder tools (Fig. 120), finish half or more with one tool and the remainder when the apron is reset and the tool changed.

115. Taper parallels or adjustable parallels (Fig. 121) are useful in gauging the width of a slot or groove; slip one past the other until the slot is filled, then measure over the two with a micrometer. Possibly in a wider groove a straight parallel may be necessary to help fill the width of the groove.

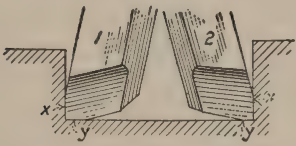


FIG. 120.—Tool bits for finishing square-shoulder cuts. Surfaces x and y are at an angle of 90 deg. or a *trifle* less.

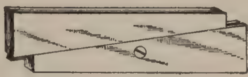


FIG. 121.—Adjustable parallel. (*Courtesy of The L. S. Starrett Company.*)

116. Planing Slots, Keyways, Etc.—A keyway tool looks like a short cutting-off tool and has the same clearance angles. When planing slots, keyways in shafts, or similar cuts, the average 14-in. shaper will carry a tool ¼ in. wide in steel or cast iron, provided a fairly light chip—0.005 to 0.010 in.—is taken. For a wider slot, two cuts or more may be necessary. If more than two cuts are necessary, take the outside cuts to (or splitting) the layout lines, then remove the metal left between.

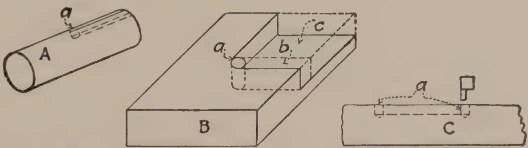


FIG. 122.—In A, diameter of drilled hole (a) equals width of keyway. In such a job as B, first, drill hole at (a), say ¼ in. in diameter; next, plane slot (b); then plane remainder (c), the cut ending in slot (b). Such a job as C requires a drilled hole at the beginning and also at the end of the keyway. Keyways such as shown in A and C are cut easier in the milling machine, but occasionally must be cut in the shaper or planer.

117. Taking Cuts Which End in the Metal.—When making a cut which terminates in the metal (Fig. 122), it is necessary to drill a hole, and in wide cuts to plane a groove, at the end of the cut, for the reason that if the chips are not cut off, they will remain to clog the cut and soon break the tool. Occasionally it is required to plane a groove, a keyway for example, some-

where between the ends of a rod or shaft (C, Fig. 122). In such a case, holes should be drilled at the beginning and end of the slot.

NOTE.—Modern shapers are constructed to permit of the end of a shaft extending beneath the ram as far as desired.

118. Planing Keyways.—It is often convenient to use a shaper to cut keyways in the hubs of pulleys, gears, etc. A forged tool for this purpose is not economical and is not much used. Figure 123 shows a homemade keyway toolholder that works well. The tool point is held in the bar b by a setscrew a at the end. The thread on the bar screwing into the holder h helps materially in holding. Bars of various lengths may be used. It is much more efficient to set up the work with the layout on *top* and feed *up* because of the tendency otherwise for the tool to chatter and jump.

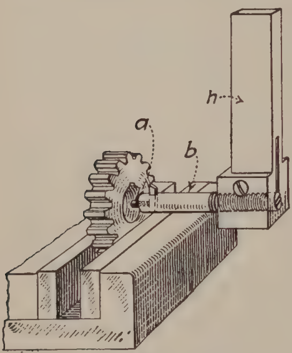


FIG. 123.—Planing a keyway in a gear. (See also Fig. 97.)

If the diameter of the work to be keyseated is fairly small, use a short bar b and let the tool post travel back and forth over the top of the work. That is, while the toolholder h is not caught especially short in the tool post, this lack of rigidity is more than made up for by the shorter bar. Such a setup is illustrated in Fig. 97, page 108.

If the diameter of the work is so large that the tool post cannot move back and forth over the blank, the bar will have to project far enough in front of the tool-post screw to go through the hole. In this case catch the tool short.

Notice that the diameter of the bar in Fig. 123 is smaller than the diameter of the hole. This is because the tool bit projects and both the bar and projecting bit must go through the hole.

It frequently happens, when holding work in the shaper vise as shown in Fig. 123, that the ram will not go back far enough. In such a case do one of three things: (1) Put one or more

parallels, as high as the vise jaw, back of the work and clamp the work between the parallels and the movable vise jaw. (2) Clamp the work in a plain vise (milling or drill press) and then clamp this vise in the desired position in the shaper vise. (Fig. 97, page 108). (3) Remove the shaper vise and clamp the work to an angle plate (paragraph 91, page 109).

The tool bit for keyseating is quite small and must be very carefully ground. The cutting edge must have clearance in order to cut, and the sides also must be backed off a little, otherwise the tool will rub. Only a very little clearance is needed. To avoid any tendency to have the top of the keyseat wider than the bottom, the cutting edge of the tool should be the widest part, but only a trifle wider; use a micrometer and be careful. Give the tool very little, if any, front rake, and no side rake.

The layout for a keyseat takes only a few moments and is usually done at the time the keyseat is made by merely scribing a radial line, using the center square. If advisable, in addition, to lay out the full width of the keyseat, it may be done quickly in the shaper vise, using a flat square and a scale. However, if several pieces are to be scribed, the full width of the keyseat, it will be best to do the layout work before setting up the machine.

Most keyseats that are planed in a shaper may be made with a full-width tool bit. Draw a radial line indicating the center position of the keyseat. Grip the work lightly at first, and, with a square, set the radial line perpendicular. Then tighten the work securely.

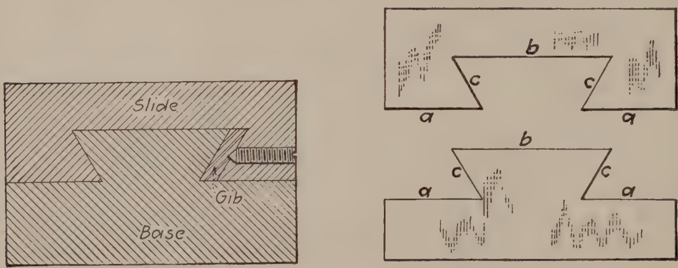
After properly setting the tool, adjust the worktable until the radial line is central with the tool. Take one stroke of the shaper by hand to be sure that there is no interference. When the tool touches the work, set the graduations at zero and feed the required depth. On account of the springy nature of the tool, use a fairly slow speed and do not feed over 0.010 in. per stroke.

If the keyseat is too wide for one cut, it is best to lay out the sides of the slot to be cut, and cut to the lines. Possibly two

cuts will make a satisfactory job, but often it is advisable to make three cuts—a full-depth "stocking" cut near the middle, and a finish cut to each line.

119. Planing Dovetails.—A dovetail slide bearing is illustrated in Fig. 124. To plane a dovetail calls for operations which are very similar to cutting a tongue and groove. If the student has not already planed a tongue and groove, his attention is called to information in detail, *applicable to dovetail*, given in paragraphs 111 to 114 inclusive.

Refer to the drawing to note if other surfaces than the dovetail are to be planed, and if so, plane them first. Finish



(*a*) (*b*)

Fig. 124.—Dovetail slide bearing.

the base surface for the reason that it is easier to lay out and work from a finished base or working surface. Then plane the other surfaces to within, say, $\frac{1}{32}$ in. of the finished size. It is best to leave about $\frac{1}{32}$ in. on both sides until after the dovetail is cut, then the sides of both the base and the slide may be easily finished in exact relation to the dovetail.

Whether it may be advisable to *rough* one angle and then turn the piece end for end, and rough the other angle, will depend upon the job. It will save the time of changing the tool and the setover of the apron if practicable. It is not considered good practice to *finish* a dovetail by planing one angle and then turning end for end; when one part of the dovetail is finished, the work should not be disturbed until the whole dovetail is finished.

The chief difference in planing the tongue and groove and the dovetail is in the planing of the surfaces *c* (Fig. 124). These surfaces, being angular, call for the setover of the *swivel head* of the shaper, also the setover of the *apron*, and for at least one pair of undercutting tools. The shape of the tools is illustrated in (7), Fig. 92. A setup is shown in Fig. 96. If considerable metal must be removed, it will probably need a roughing and finishing tool for each side.

Assuming the base and sides are already planed, or at least squared up, the surfaces *b* in Fig. 124 and the greater part of the surfaces *a* should be roughed practically as for tongue and groove, and, without disturbing the setting of the work, the surfaces *c* and the portion of the surfaces *a* under the overhang may then be roughed. The finishing operations are made in the same order. The tool that is used for finishing surface *c* may be properly used for surfaces *a* and *b*, provided the tool is not too slender and the surface is not too large. The beginner should pay particular attention to the swivel of the apron. Remember that when *not* properly set it may appear all right, and therefore be *very sure* that the *top* of the apron is set in a direction *away* from the surface being planed.

120. Measuring Dovetails.—Probably the greatest difficulty in producing dovetails is in measuring them. When a gib[1] is used between two of the sliding surfaces as great a degree of accuracy is not required in planing as when the two pieces fit together. In either case, however, a smooth cut is necessary, a thousandth or two should be left for scraping, and care must be taken not to "leave too much," and certainly not to "take off too much." It is good practice to lay out the dovetail and if possible it should be scribed on a surface that has been finished. If several pieces are to be planed,

[1] *Gib.*—In machine construction a piece of metal arranged to provide an adjustment for a bearing. In *a*, Fig. 124, is shown a cross section of a *straight gib* between two bearing surfaces and adjusted by a series of screws. Frequently *taper gibs* are used, and the dovetail in the base is made correspondingly wider at one end. Such a gib is adjusted lengthwise to take up the wear in the bearing surfaces.

it will be advisable to make a template of sheet metal ⅛ to ¼ in. thick to use for laying out and possibly as a gauge.

The table given below should prove helpful in making accurate measurements of dovetails to find how much more it may be necessary to plane an angular surface and also to check the finished product. It consists of a series of fixed values for determining the measurements for various angles of dovetails when using various sizes of drill rod.

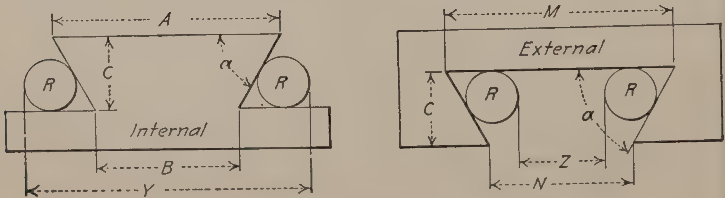
At first glance the table may appéar rather difficult, but its use involves only addition, subtraction, and multiplication of decimals. In principle it is similar to the three-wire method of measuring threads and its application is just as easy.

MEASURING DOVETAILS WITH PIECES OF DRILL ROD

In the table, R is the diameter of the drill rod and the values of D and F have been calculated as follows:

$$D = R\left(\cot \frac{\angle a}{2}\right) + R. \qquad F = 2 \cot \angle a.$$

Various diameters of drill rod		Various values of angle a			
		45°	50°	55°	60°
$R = ¼''$	$D =$	.853	.786	.730	.683
$R = ⅜''$	$D =$	1.280	1.179	1.095	1.024
$R = ½''$	$D =$	1.707	1.572	1.460	1.366
$R = ¾''$	$D =$	2.562	2.358	2.190	2.049
	$F =$	2.000	1.678	1.400	1.155



(a) (b)

FIG. 125.—Measuring internal and external dovetails.

RULES

Internal

Case I.—When the dimension B is given on the drawing.

$$Y = B + D$$

Example.—Angle $a = 60°$, $B = 2\frac{1}{2}''$. Using $\frac{1}{2}''$ drill rod, what should Y measure?

Solution.—$Y = 2.5'' + 1.366'' = 3.866''$.

Case II.—When the dimension A is given on the drawing it is necessary to find dimension B before proceeding further.

$$B = A - CF$$

Example.—Angle $a = 60°$, $A = 3''$, $c = \frac{3}{4}''$. Using $\frac{1}{2}''$ drill rod, what should Y measure?

Solution.—First find dimension B thus: $3'' - 0.750'' \times 1.155 = 3'' - 0.866'' = 2.134''$.

Then $Y = 2.134 + 1.366 = 3.5''$.

External

Case I.—When the dimension M is given on the drawing.

$$Z = M - D$$

Example.—Angle $a = 60°$, $M = 3''$. Using $\frac{1}{2}''$ drill rod what should Z measure?

Solution.—$Z = 3'' - 1.366'' = 1.634''$.

Case II.—When N is the dimension given on the drawing it is necessary to find dimension M before proceeding further.

$$M = N + CF$$

Example.—Angle $a = 60°$, $N = 2''$, $c = \frac{3}{4}''$. Using $\frac{1}{2}''$ drill rod what should Z measure?

Solution.—First find dimension M thus: $2'' + 0.750'' \times 1.155 = 2'' + 0.866'' = 2.866''$.

Then $Z = 2.866'' - 1.366'' = 1.5$

Note.—The measurement of Z may be made with adjustable taper parallels placed between the rods (see paragraph 115).

121. The Vertical Shaper.—The vertical shaper (Fig. 126) is much used in general machine shops and tool-making departments. The worktable with longitudinal, transverse, and rotary feeds, both hand and power, gives certain advantages; for example, a variety of power-fed cuts, straight and curved, with the layout lines always in plain sight of the operator.

The construction of the vertical shaper has many points in common with the standard (horizontal) shaper. The operation of the two types are very similar as to tools used, feeds, speeds, layout, and measurements.

The illustration and the definitions of parts are included in this text for two reasons: first, as information concerning an excellent machine; second, as an example of the fact that if the student understands the construction and operation of a standard machine tool, that information may be applied in the study of any type of similar machine.

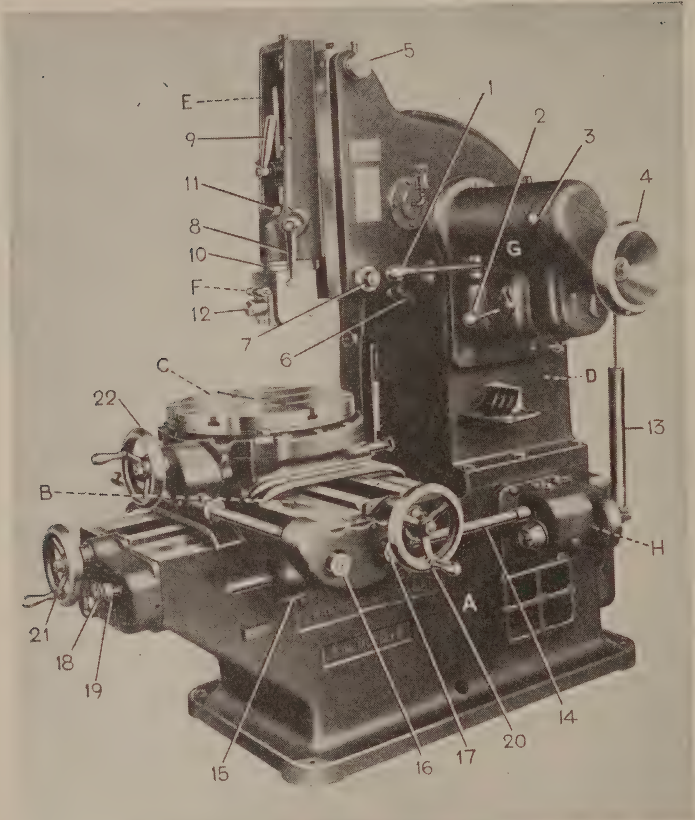


FIG. 126.—The vertical shaper. (*Courtesy of Pratt & Whitney Company.*)

PARTS OF THE VERTICAL SHAPER

Index to Unit Names

A. *Bed*, a very rigid support for the column *D*, saddle *B*, and the worktable *C*.

B. *Saddle*, has hand and power transverse (cross) feed on the finished surface of the bed. Carries the worktable *C*.

C. *Worktable*, has hand and power longitudinal feed on the saddle, also has hand and power rotary feed. These feeds, together with the transverse feed of the saddle, allow straight cuts, longitudinal and transverse, also circular, convex and concave cuts, to precision outlines, by hand or power feed. The rotary table is provided with twelve indexing notches and a detent plunger. A lever disengages the worm when advisable, and a binder for locking the table in position is provided.

D. *Column*, carries the ram *E*, and the speed-gear box *G*. Also carries (not shown) the bull gear, slotted arm, link, etc., for driving the ram.

E. *Ram*. The ram, which carries the toolhead, slides in a dovetail in the ram guide. The ram may be adjusted for length of stroke and position of stroke. Also, the ram *guide*, being heavily hinged (5) at the top, and having a screw adjustment (6) at the bottom, may be swung outward any angle up to 5 deg. and locked in position. This is useful, for example,

Questions on Shaper Work II,

1. Given a rectangular block, say, 2 by 6 in. and 1 in. thick, which side should you plane first? Which side will you plane next?

2. After planing the first surface, what objection is there to planing the opposite surface next?

3. Why is the surface that has been planed placed against the solid jaw of the vise?

4. Why is a strip placed between the movable jaw and the work?

5. When planning the third (and fourth) surfaces the use of two parallels, as far apart as convenient, is advisable. Why?

6. How does the arrangement suggested in the preceding question aid in making accurate measurement?

7. How are the ends planed when the piece is short? When the piece is over 6 or 8 in. long?

---

for planing the clearance on blanking and piercing dies. A positive stop is provided for exact vertical position.

F. *Head.* A feature of the vertical shaper is the swivelling toolhead. To adjust to any position through 360 deg., loosen the binder nut (11), turn to correct position and tighten the binder. Graduation lines are 90 deg. apart.

G. *Speed gearbox.* Power comes from the main driving pulley (not shown) through drive shaft to sliding gears in the gearbox to give four speeds to the ram.

H. *Feed gearbox,* contains the feed-reversing gears and clutch, also the feed ratchet and pawl.

Index to Part Names

1. *Friction-clutch control lever,* for ram drive; has three positions: (1) power on, (2) neutral, (3) brake. The ram is driven, similarly as in a standard shaper, by a crankpin and driving block, adjustable toward or away from the center of the bull gear. The block, more or less off-center, depending upon the stroke desired, drives the slotted arm (rocker arm) which is connected to the ram through a link.

2. *Gear-shift lever,* in H plate, for four speeds and neutral position. A plate on the side of the column gives the available cutting speeds, both as ram-strokes-per-minute and cutting-feet-per-minute.

3. *Cover* under which are lock nuts for changing length of stroke of ram. The feed cam and the bell-crank cam follower (see 13 below) are also under this cover.

4. *Handwheel* for moving positioning ram.

5. *Hinge* of ram guide, for angular adjustment, up to 5 deg., of ram.

6. *Turnbuckle* for adjusting ram to angular position.

7. *Binder* for angular adjustment of ram.

8. *Crank* which operates vertical screw for positioning the ram vertically.

9. *Binder* for ram (loosen before and tighten after positioning ram vertically.)

10. *Swivel* for toolhead.

11. *Binder* for toolhead swivel.

12. *Tool post,* carried in clapper block and has same action as in standard shaper. The tool, however, is held by drawing the tool post against it from the back by a nut. This does away with the projecting tool-post screw.

13. *Feed rod,* has vertical oscillating motion imparted by the feed cam under the cover (3), which, through a bell-crank follower, moves a rocker and an adjustable rocker nut. The feed rod, connected to the feed-rocker nut above, and the pawl carrier below, gives motion to the pawl and ratchet in the feed gearbox *H*, thence through the gears to the feed shaft (14).

14. *Feed shaft,* transmits motion from gears in *H* to spiral gears (15).

15. *Spiral gears* which transmit power for all automatic feeds of table. These feeds are controlled by handles 16, 17, 18, and 19.

16, 17, and 18. *Handles* for slip gears for engaging rotary feed, longitudinal feed and transverse feed, respectively, of worktable.

19. *Handle* for reversing all automatic feeds.

20, 21, and 22. *Handwheels* for table feeds, longitudinal, transverse, and rotary, respectively.

8. How is short work adjusted in the vise to make sure it is square when planing the ends?

9. Is a coarse feed or a fine feed used in finishing a cast-iron surface in a shaper? For finishing steel?

10. What kind of a tool is used for finishing cast iron? For steel?

11. In planing cast metals, what precautions should be taken to prevent the metal breaking out at the end of the cut?

12. Why is it necessary to get under the scale when cutting cast iron?

13. What is a forming tool? Why is a spring toolholder excellent for holding a forming tool?

14. How is a comparatively narrow irregular surface planed?

15. After roughing out a wide irregular surface how is the edge bevelled? What is the object of the bevel?

16. What kind of a tool is used for finishing the sides of a tongue? The horizontal surfaces?

17. How may the groove be accurately and quickly measured?

18. Strange as it may seem, the cutter for keyseats works better up than down. How do you account for this?

19. When required to cut a keyway in a shaft a certain distance why do you first drill a hole at the end of the keyway?

20. What tool is used for finishing the angular surface of a dovetail?

21. State two distinct operating advantages of the vertical shaper.

THE PLANER

CHAPTER VI

PLANER CONSTRUCTION

122. Introduction to Planer.—The function of the planer is the production of flat surfaces on work that is too large or otherwise impracticable or impossible to machine in the milling machine or shaper. The work is fastened on the worktable or

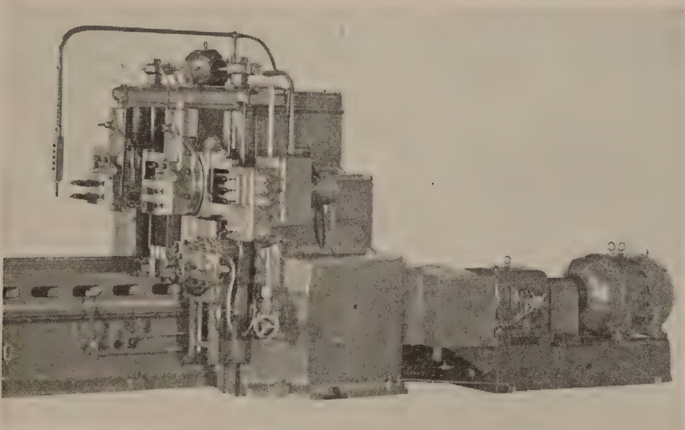


FIG. 127.—A modern hydraulic planer with four heads. The pump-driving motor, the *Oilgear* pump and the oil reservoir are shown at the right. (*Courtesy of The Rockford Machine Tool Company.*)

"platen" which has a reciprocating motion past the toolhead. The tool cuts only on the forward or cutting stroke of the planer platen and is held stationary except for the feeding movement. The feed may be in a horizontal direction across the top of the work by reason of the movement of the toolhead along the crossrail, or in a vertical or angular direction

through the downward movement of toolhead slide. The operation of the feeds will be explained later.

The single-point cutting tool produces a more accurate surface and a surface much better adapted to the scraping operation than a milled surface. Each of the standard machines in the shop has its particular advantages, and while the larger sizes of milling machines have taken the place of the planer in certain classes of work, they cannot compete with the planer in the production of flat surfaces that must be finished smooth and true. For example, such machine-tool parts as lathe carriages, the bottoms of headstocks and tailstocks, the sliding surfaces of shaper columns and rams, also shaper tables, worktables of grinding machines, milling machines, etc., are planed. For the bases, frames, and heavier sliding parts of such machines as steam engines, locomotives, printing presses, and rolling-mill, wood-working, and textile machinery, etc., the planer is indispensable.

The general run of planing is very accurate work and calls for a high degree of skill. Planer work should prove very interesting. First-class planer hands are hard to find and consequently are among the best paid mechanics in the trade.

To be able to handle a planer, the operator should understand, first, the general construction of the machine, especially the driving mechanism, the feed mechanism, the toolhead, and the adjustment of the crossrail which carries the toolhead; second, the various methods of clamping the work, which operation, on the planer, probably calls for more skill than in any other machine-shop tool; third, how to obtain the cutting action of the tools used which will give the best results.

The difference in handling the various types and sizes of planers is, for the most part, in degree of experience and skill required for the given job. As a matter of fact, some of the most exacting and interesting work is done on the smaller planers.

NOTE.—A modern four-head planer having hydraulic-drive and -feed mechanisms is shown in Fig. 127. References in this chapter apply more

particularly to the standard gear-driven planer. Hydraulic power transmission for machine tools is discussed in Chapter XVII.

123. Parts of the Planer.—In order to understand certain necessary descriptions which follow it will be advisable for the beginner to become familiar with the names and functions of the planer parts. In a general way the names and descriptions given in the following pages apply to any standard planer of whatever make.

124. Size of Planer.—Planers are classified as to size by the distance between the housings, the distance between the platen and the crossrail at its highest position, and the maximum stroke, for example, the planer illustrated Fig. 128 is 24 by 24 in. by 6 ft.

The smaller planers have only one toolhead; the larger planers have two heads with independent feed screws. Planers 28 in. wide and over may be provided with a sidehead mounted on the face of each housing. In such planers the finished faces of the housings are long enough to permit of the sideheads being run down below the top of the table (see Fig. 130).

Perhaps a larger range of sizes obtains in planer manufacture than in any other machine tool except the lathe, but fortunately, in the planer as in the lathe, the principles of construction and operation are practically the same for any size.

125. Openside Planer.—The value of the openside planer (Fig. 129) consists in its adaptability for planing parts much wider than would pass between the housings of an equal size regular planer. For ordinary duty it is not meant to supersede the regular type, but it is a practical machine for the purpose for which it is intended.

The openside planer, with one column, has been designed to give sufficient strength and rigidity to resist the severest twisting forces to which it may be subjected. Vertically adjustable on the front face of the column is the knee, which, when set in position, may be rigidly locked. The massive column construction, together with the strength and stability

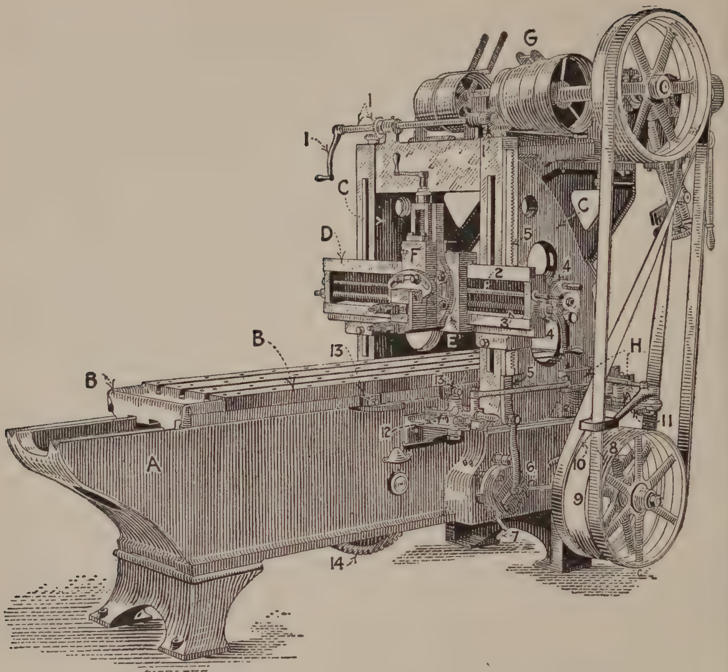


Fig. 128.—Planer. (*Courtesy of G. A. Gray Company.*)

PARTS OF THE PLANER

Index to Unit Names

A. *Bed*, of deep box section, with cross girths to give strengt hand stability. V tracks accurately machined and scraped provide sliding ways for the table or "platen."

B. *Table or "platen,"* provided with T slots and reamed holes for purposes of clamping or otherwise holding the work.

C. Uprights, or "housings," or "posts." These very rigid supports for the crossrail are securely bolted and pinned or tongued to the bed. The front faces are machined and scraped to be parallel to each other, in perfect alignment, and square with the bed. They are tied together at the top by the "arch" to give greater strength and rigidity.

D. *Crossrail*, carries the saddle and toolhead. May be raised or lowered and clamped in the desired position on the finished faces of the housings. (Release the clamps before adjusting.)

E. *Saddle*, supports the toolhead, may be moved along the rail by hand or power.

F. *Toolhead*, is firmly fastened to saddle, which is accurately scraped to the crossrail, with taper gib adjustment for wear. Has automatic cross-feed on the rail, and the toolhead slide and screw provide for vertical and angular feed. The feeds may be operated by hand from either side of the machine. Angular position of the head is indicated by graduations in degrees. Downfeed screw is provided with graduated dial reading in thousandths of an inch (for details see Fig. 131).

G. *Speed variator.* For part names see Fig. 114.

H. *Belt-shifting mechanism.* For description of principle of mechanism see page 153.

I. *Feeding mechanism.* Numbers 3 to 7. For detail see Fig. 136.

J. *Driving and reversing mechanism.* Numbers 8 to 14.

of the knee, affords a support for the crossrail that prevents deflection under the heaviest cuts.

A steel hold-down gib, full length of the platen, runs in a flood of oil under a flange in the bed, to prevent any side tipping of the platen due to the weight of the overhanging part of a heavy casting. Also, a floor rest for supporting the real wide pieces is made and furnished as an extra. When this is used, the overhang of the work is fastened to the rest which moves back and forth on suitable rollers.

126. Modern Planers.—The larger standard and openside planers have many advanced features of construction such as: rapid traverse of any head in either direction; positive dial-set feeding mechanism, for all heads, from $\frac{1}{64}$ to 1 in. feed; special motor-driven rail-setting devices; double-length bed to eliminate overhang of platen; safety clutches to prevent the feeding of any head too far, or of one head hard against the other; centralized and forced positive lubrication, with filtered oil, of all bearings; and balanced helical-gear drive from pulley shaft to the table rack. A modern four-head gear-driven planer is shown in Fig. 130.

Index to Part Names

1. *Handle, shaft*, and *bevel gears* for raising or lowering the crossrail. Motion is transmitted to vertical screws, one back of the face of each upright. It is essential that the crossrail clamping bolts or levers are loosened before attempting to change the position of the crossrail, or the gears and threads will be strained and possibly ruined.

2. *Feed rod* for downfeed, operates through bevel gearing to downfeed screw in toolhead.

3. *Feed screw* for cross feed, operates to feed the saddle (and toolhead)along the crossrail. Provided with graduated collar reading in thousandths of an inch.

4. *Feed gears*, operate ratchet-and-pawl mechanism transmitting the feed motion to either the feed rod or the feed screw. (The small gear, "trigger gear," which in some planers encloses the ratchet and pawl, may be changed from feed rod to feed screw as desired.)

5. *Feed rack*, operates feed gears (4).

6. *Rocker* on friction, connected by link to feed rack and moves feed rack up and down (friction described, paragraph 137.)

7. *Handle* for adjusting the amount of feed. (Also the position of the nut on the adjusting screw one side or the other of center of rocker slot determines whether the feed will operate at the end or at the beginning of the cutting stroke).

8. *Loose pulley* for carrying the reversing belt when it is off the tight pulley.

9. *Tight pulley*.

10. *Loose pulley* for carrying the driving belt when it is off the tight pulley.

11. *Belt-shifting device* (cam action) operates at the end of the cutting stroke to shift the driving belt off the tight pulley and the reverse belt on. At the end of the return stroke this operation is reversed (explained more fully on p. 128).

12. *Shifter lever* operates the belt shifting device (11) to reverse the motion of the platen when moved either automatically by means of the dogs (13) or by hand. Also operated by hand to bring the shifting device to neutral position with both belts on the loose pulleys. In this manner the platen may be stopped without stopping the machine.

13. *Dogs*, adjustable along the side of the platen. The positions of these dogs determine the length and "position" of the cutting stroke.

14. *Driving gear* or *bull wheel*, engages a rack fastened to the platen and extendnig the length of the platen (see paragraph 131).

In the smaller planers improvements in design are also apparent. They have more rigid construction all through: bed, housings, platen, rail, and gears; improved oiling system; a refinement in many details of design and construction of the bearings, slides, screws, and gears to meet the demand for higher-speed, quicker-acting machines.

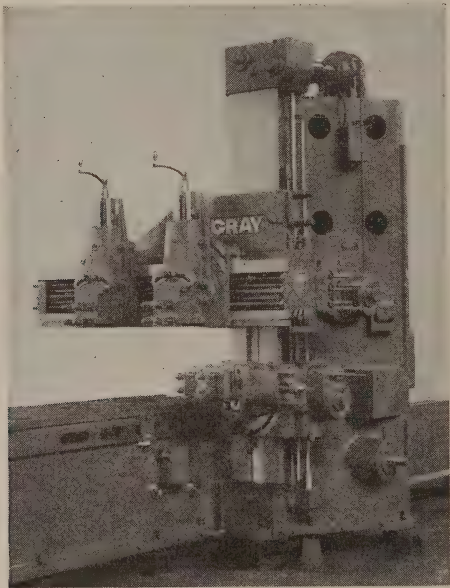


Fig. 129.—Open-side planer with one vertical, and two horizontal toolheads. (*Courtesy of The G. A. Gray Company.*)

A very considerable amount of fine accurate work was done on planers fifty years ago, but in the modern machines *quality* may be produced *more easily and quickly*. The planer hand today has better machines, better tools, better working conditions, and he must be alert to take advantage of modern machines with their greater speeds.

UNITS OF PLANER CONSTRUCTION

127. The planer bed is particularly heavy and is designed for strength and rigidity under great weight and heavy duty.

The ways for the platen sliding surfaces are planed and scraped. They are automatically oiled under pressure through pipe lines from a reservoir or, in the older models, from oil wells suitably located. These wells should be filled every week and occasionally should be cleaned. The ways must be smooth and true if accurate work is to be expected.

FIG. 130.—A modern planer with four heads—two on the crossrail and two sideheads. (*Courtesy of The Cincinnati Planer Company.*)

Careless and ignorant operators frequently lose sight of this fact, and gritty dust and dirt are allowed to settle on the ways, in fact are often brushed into the ways. Be careful, remember that proper attention directed to the care of machinery marks the *real mechanic* whether he is the operator or the superintendent.

128. The planer platen supports the work. It is provided with accurately finished T slots for the work-holding strips or fixtures and the necessary bolts. It is also provided with reamed holes for stops, poppets, etc. The platen is made of the best cast iron. For the sake of permanency in its finished shape it is rough-planed and then allowed to "season" a reasonable length of time before it is finish-planed and the

sliding surfaces scraped. To make for accuracy, the top is planed on its own bed before it is shipped.

The platen is *not* an anvil nor is it a suitable depository for half the bolts, clamps, and wrenches in the shop. The holes are accurately reamed to size and care should be taken to keep them round and smooth. Put a little oil on the stops or other planer "furniture" before you wring or tap them into the holes (never *hammer* them in). Two or three strips of old belting placed across the platen protects it when placing heavy castings. After the piece is in position it may be lifted, perhaps with a pry, and the belting removed.

129. The crossrail carries the saddle and toolhead. It is adjustable vertically on the finished front faces of the housings by means of two vertical screws; one in each housing. Both screws are moved an equal amount by turning a horizontal shaft arranged above the housings; motion of the shaft being transmitted through bevel gears to each screw at the same time. In the smaller planers the shaft is squared on the end to receive a crank, in the larger planers, 36 by 36 in. and over, a power elevating device is provided.

The crossrail should be clamped rigidly to the housings when in use, and it must be remembered to loosen the clamps when adjusting for height.

The crossrail is of box-section construction enclosing the feed rod for power downfeed and the feed screw for the regular cross feed. Great care is taken to have the surfaces on the back scraped to an accurate flat bearing on the housings, and the surfaces for the saddle bearing perfectly fitted and parallel. The elevating screws are arranged to adjust the crossrail equally on each end, but for accurate work care must be taken that the rail when clamped is parallel to the platen.

To make sure the rail is parallel to the platen lower it on suitable parallels arranged each side of the platen and then clamp. Another way is to tighten an indicator in the tool post with the point touching the platen and note the reading as the head is run across the rail. Possibly one of the bevel (driving) gears will have to be readjusted.

130. The Toolhead (Fig. 131).—In construction and operation the planer head is very similar to the shaper head. As in the shaper head the vertical adjustment of the tool is made by turning the downfeed screw handle. The *planer head*, however, is always provided with power downfeed,

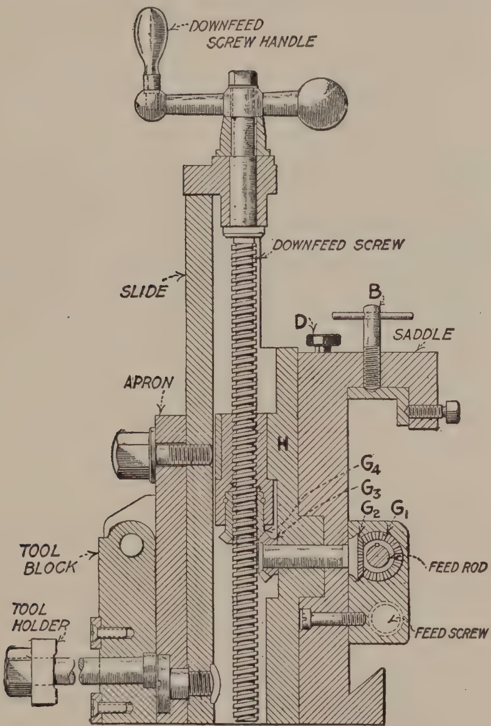


FIG. 131.—Vertical section of planer head.

motion being transmitted from the feed rod through a toothed clutch feathered on the rod, thence through two pairs of bevel gears, G_1 and G_2, G_3 and G_4, to the downfeed screw. When power downfeed is to be used, the gear G_1 is engaged with G_2 by turning a small knob or lever D.

The toolhead slide is mounted on a swivel plate or "harp" H which is fastened to the saddle by two or more clamping bolts. When the bolts are loosened slightly the head may be

swiveled through an angle of 90 deg. either side of its vertical or normal position. Graduations in degrees indicate the angular setting. Similarly as in the shaper head the *apron* may be set over either side in order that the tool may clear the work when taking a vertical or angular cut (see page 120).

A saddle-binder screw *B* is provided for holding the saddle rigidly in position when taking a vertical or bevel cut and a toolslide binder screw is provided for holding the toolslide when taking a horizontal cut. Do not forget to loosen these screws when it is desired to move either part. *Remember always that every moving part of a machine should move freely.*

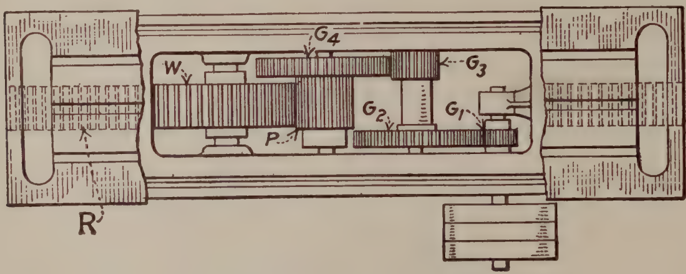


FIG. 132.—Diagram of planer-driving gear train.

131. Planer-driving Mechanism.—The planer platen is driven by means of a gear meshing with a rack which is fastened on the under side of the platen. In most planers the driving gear is fairly large in proportion, and especially rugged in design, and is often termed the "bull wheel." There are two features of the planer-driving mechanism that are especially interesting: (1) the gearing which serves to reduce the speed between the driving pulley and the bull wheel, and (2) the mechanism which causes the reversal of the direction of rotation of the bull wheel to give the forward and return movement of the platen.

The diagram in Fig. 132 illustrates the extended gear train or bull-wheel drive. Motion is transmitted from the countershaft to the tight and loose pulleys by means of an open belt for the forward stroke and a crossed belt for the reverse. This motion is further transmitted and the speed reduced by

the two pairs of reducing gears G_1 and G_2, G_3 and G_4. The bull-wheel driving pinion P is keyed to the same shaft as G_4 and being engaged with the bull wheel W and much the smaller of the two, serves to transmit motion to the bull wheel at still further reduced speed. The bull wheel engages the rack R which is fastened to the under side of the platen; consequently the platen moves forward or backward, according to the direction of rotation of the bull wheel. Figure 133 shows the drive of the planer illustrated in Fig. 128.

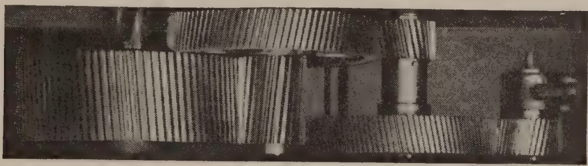


FIG. 133.—Planer drive, view looking down, platen (and rack) removed. All gears are helical, including the bull pinion, bull gear, and rack, and run in a bath of filtered oil. (*Courtesy of The G. A. Gray Company.*)

132. Quiet-running Qualities of Planer.—Great care is taken in the design and construction of planers to insure smooth running and long life. The gears are of ample size cut from the solid with special cutters made for the particular number of teeth in each gear. The shafts and bearings are proportionally large, in fact, the whole machine is especially rugged. If proper care is taken to keep the ways and other flat bearing surfaces cleaned, all of the bearings, round and flat, properly oiled, and the gears well greased, a planer will keep quiet and do its work indefinitely. The boy who has learned to use a piece of waste and an oil can *intelligently* on the machine he is running has gone a long way toward understanding the construction of the machine.

133. Reversing Mechanism.—In any belt-driven planer there are two belts, one "open" and one "crossed," which serve in turn to transmit motion from the countershaft to the tight and loose pulleys of the planer-driving mechanism. Some planers have one tight pulley and two loose pulleys all of the same diameter, others have two pairs of pulleys of

different diameters one tight and one loose in each pair, the larger pulleys for the "cutting" belt and the smaller for the return belt. In either case belt shifters operate automatically when the machine is running, to shift the cutting belt off the tight pulley onto its loose pulley, and the return belt off its loose pulley onto the tight pulley at the end of the cutting stroke, and the reverse at the end of the return stroke.

The belt shifters are moved by means of a camplate operated through a series of two or more lever arms which are controlled by a slight movement of the initial shifter lever (12, Fig. 128) on the side of the planer. The end of this shifter lever opposite the handle projects far enough beyond the pivot pin to reach nearly to the platen, consequently the dog (13, Fig. 128), fastened to the moving platen, comes in contact with the lever, and causes a movement of the lever, a shifting of the belts, and a reverse movement of the platen. This movement will continue until the other dog pushes the lever in the opposite direction. The distance apart of the dogs determines the length of stroke and where they are located on the platen determines the "position" of the stroke.

The purpose of the camplate is to move the belt shifters in such a way that the one belt is completely off the tight pulley before the other is on, to avoid any tendency of the belts to pull against each other.

This feature of construction has the added advantage of making it possible for the operator with a slight movement of the shifter lever, by hand, to run both belts on the loose pulleys thus stopping the platen without stopping the machine. A safety locking pin is provided to prevent accidental starting of the platen. The operation of the belt-shifting mechanism is illustrated in Fig. 134.

134. Planer Speeds.—The single-speed planer, with a cutting speed of from 30 to 40 ft. per min. and a return speed of from two to four times as fast, has been regarded as standard equipment. The single-speed planer may still be regarded as suitable in shops having a large amount of uniform planer work, provided the speed is arranged in the first place for

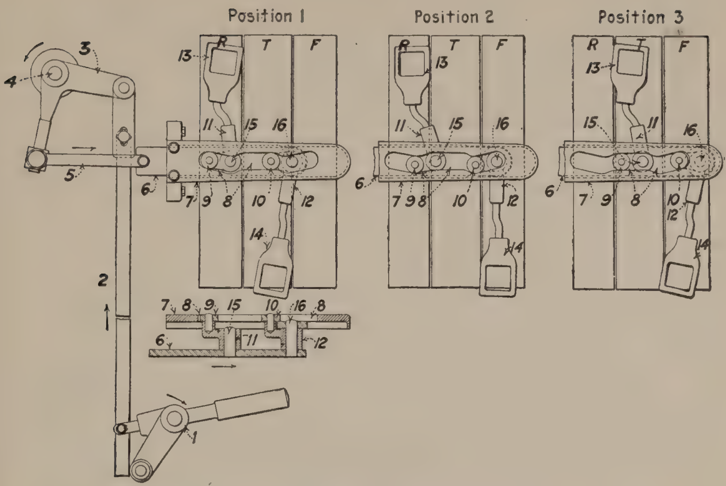


FIG. 134.—Belt-shifting mechanism.

The dogs on the side of the planer platen serve to move the lever (1). The lever (1) moves the rod (2) and this operates the bell crank (3) pivoted at (4) and causes a movement of the rod (5) and also the sliding bar (6). Directly over the sliding bar is the camplate (7) which is fastened to the side of the planer. The cam slot (8) is cut in the camplate, and (9) and (10) are rollers which fit the sides of the slot. The studs on which these rollers are carried are mounted respectively on the short arms of the bell cranks (11) and (12) the long arms of which carry the belt guides (13) and (14). The bell cranks, being pivoted on the sliding bar (6) at (15) and (16), move with the sliding bar, and as the rollers (9) and (10) on the short arms of the bell cranks follow the outline of the cam slot, the belt guides (13) and (14) are moved in accordance with the movement of these rollers in the cam but a greater distance due to the greater lengths of their lever arms. That is, the parts of the cam slot not parallel with the line of motion of the sliding bar (6) serve to move the short arms of the bell cranks and cause the belt guides to move a considerable distance over the pulleys.

The cam slot is so made that when the sliding bar (6) is in the "position 1" the reverse belt guide (13) is over the loose pulley *R* and the cutting-belt guide (14) is over the tight pulley *T* which is keyed to the driving shaft.

When the sliding bar (6) moves to "position 2" the belt guide (13) remains over the pulley *R* because the roller (8) following the slanting part of the cam slot serves to move the belt guide (13) back as the bar (6) is moved forward. That is, the belt guide (13) is moved back far enough to compensate for the movement of the sliding bar (6). The belt guide (14), however, moves over the loose pulley *F* because the roller (10) following the more abrupt curve in the cam slot throws the belt guide (14) over twice as far as the bar (6) moved. Therefore, in "position 2" the belts both are on loose pulleys.

When the sliding bar (6) moves to "position 3" the guide (13) moves over the tight pulley *T* similarly as when the guide (14) was moved to "position 2," and the guide (14) remains over the loose pulley *F* similarly as the guide (13) did in moving to position 2.

Reversing the direction of the guide plate reverses the above movements.

the particular kind of work. However, the cutting speeds suitable for planer tools are governed by the same general conditions that obtain in other machine tools, and therefore multispeed planers must be recognized as most economical for general work. See Table of Planer Speeds, page 478.

135. Speed Variator.—The various planer manufacturers have developed simple and effective means of quickly changing

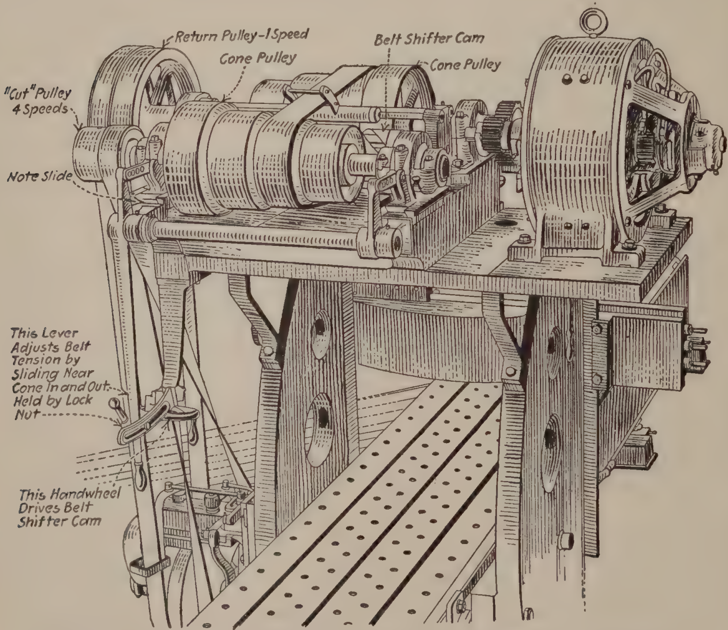


FIG. 135.—Planer-speed variator. (*Courtesy of The G. A. Gray Co.*)

the cutting speed. The "speed variator" as it is called, is usually mounted on a plate on top of the housings. One type of speed variator is illustrated in Fig. 135. Four speeds are obtained through a pair of opposed four-step cone pulleys connected by a belt. One of these pulleys is mounted on a constant-speed shaft which may be driven by a belt directly from the line shaft or by a silent chain or by gears from a motor placed with the variator on the plate. On the end

of this constant-speed shaft is the return-stroke driving pulley. Consequently the return of the planer platen is constant. The other cone pulley is mounted on the variable-speed shaft on the end of which is the cutting-stroke driving pulley. Consequently four speeds may be given this pulley. The belt is moved from step to step on the cones by a conveniently arranged handwheel or lever. On the smaller sizes of the planer the variator is usually arranged for the following speeds: 25 ft., 33 ft., 42 ft., 50 ft. per min. cutting speeds and 100 ft. per min. return speed, and on the larger sizes of planers, 22 ft., 30 ft., 37 ft., 45 ft. cutting speed and 90 ft. return speed.

The larger sizes of planers, however, are best equipped with a variable-speed reversing motor directly connected to the initial driving shaft of the planer by means of a coupling. This variable-speed drive is especially efficient, and with it any one of a wide range of cutting speeds, and also return speeds, is available.

136. Feeding Mechanism.—When planing a horizontal surface the feed is accomplished by causing the feed screw to move, thus causing the head to move along the crossrail. When planing a vertical or an angular surface, the feed is accomplished by causing the downfeed screw in the head to move.

The end of the feed screw is squared on the end to receive a handle which is used for adjusting the head to the required position on the crossrail, or for hand feed if desired. Likewise the end of the feed rod is squared, and the handle may be removed from the feed screw and put on the feed rod for adjusting the head vertically, if the bevel gears G_1 and G_2 (Fig. 131) are engaged. However, most vertical adjustments of the tool are made directly by using the downfeed screw handle, the feed rod being primarily for the purpose of automatic downfeed.

A ratchet-and-pawl mechanism is used in transmitting the automatic or power feeds, and in many planers this mechanism is contained within a gear frequently called the "trigger gear" (Fig. 137).

In addition to being squared to receive the feed handle both the feed screw and feed rod are turned the same size, and keyed, to receive the trigger gear.

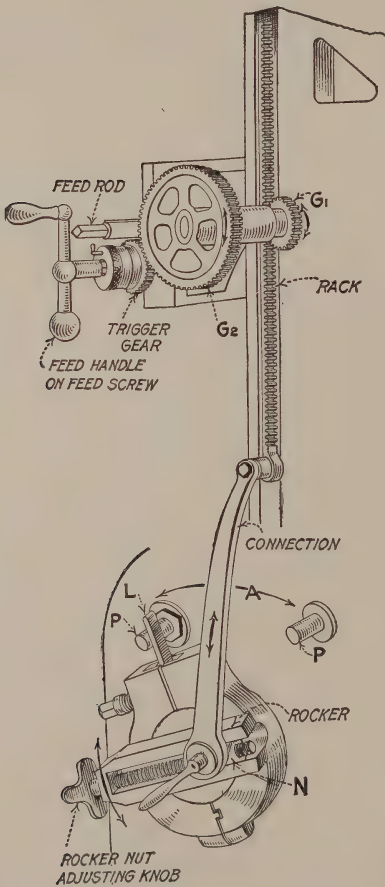


Fig. 136.—Planer-feed mechanism.

By referring to Fig. 136 which illustrates a common type of feeding device, it will be observed that motion is transmitted from the rocker, through a connecting link to the rack, thence through the gears G_1 and G_2 to the trigger. The trigger

gear meshes with gear G_2 when on either the feed screw or the feed rod.

The rocker moves through a part of a revolution at the beginning of each forward stroke of the planer and back on

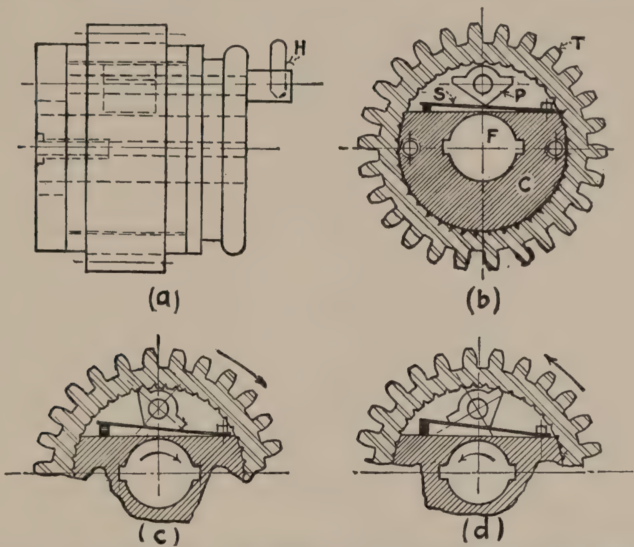


FIG. 137.—Inclosed type of feed gear, ratchet and pawl, or "trigger gear." The pawl carrier C is a bushing fitting over the feed screw F or the feed rod as the case may be, and fitting freely within a fairly large hole in the gear T. A portion of the bushing is cut out to receive the trigger type of pawl P and the flat spring S that holds it in place. Notches are cut lengthwise through the hole in the gear to form the ratchet teeth. The handle H serves to change the trigger to any one of three positions as shown in (*b*), (*c*), and (*d*). The oscillating movement of the gear T serves, in one direction, to move the pawl carrier and operate the feed, and in the other direction, to move the gear one or more teeth over the trigger, ready for the next feeding motion. The position of the trigger determines the direction of the movement of the carrier and consequently the direction of the feed. This is shown in (*c*) and (*d*). In (*b*) the pawl is neutral and there is no feed.

the return stroke; consequently an oscillating movement is given to the trigger gear. The amount of this movement is governed by the distance the rocker-arm nut N is *off center*, and whether the movement will be at the beginning of the forward stroke or the return stroke is determined by the position of the nut *one side or the other of the center*. Regard-

less of the length of stroke, the operation of the feed takes place during 4 or 5 in. of the stroke. Except on the shorter cuts, it is customary to have the feed operate at the beginning of the forward stroke. Since the feed should take place *before the tool starts to cut,* the stroke is set 4 or 5 in. longer than the work.

137. The Feed Friction.—The principle of the friction which operates the rocker for this rapid feed motion during a portion only of the travel of the platen is an important feature of planer design.

The feed friction, one type of which is illustrated in Fig. 138, is usually at the end of one of the shafts of the driving-gear

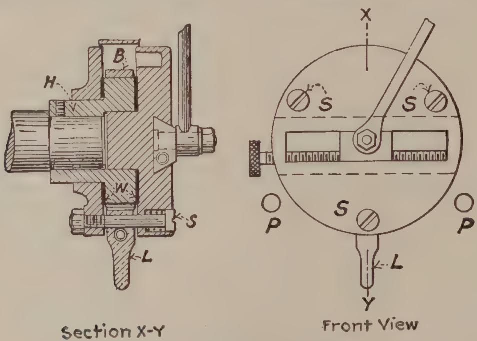


FIG. 138.—Planer feed friction.

train. The hub *H* is keyed to the shaft, consequently is turning in one direction or the other all the time the planer is running. A leather (friction) washer *W* is arranged on each side of the enlarged end of the hub, and the front plate of the friction (which carries the rocker) and the rear plate are pressed against these washers under spring tension by three or more screws. The friction band *B* practically surrounds the hub, and the lever *L* is so arranged that when it strikes each stop *P*, it opens the band a trifle and releases it from the hub.

At each reversal of the driving-shaft motion, the rocker travels through a part of a circle determined by the relative positions of the stop pins *P*. At this time both frictions on

the hub operate, and the combination of the two is sufficient to move the feed rack, feed gears, ratchet and pawl, etc., and give the cross-feed or downfeed desired. During the rest of the planer stroke the face friction alone operates since the band is released when the lever strikes either stop. The face friction serves to keep the lever against the stop and the band open. On the smaller-size planers the combination of two frictions is not necessary and one only is furnished. If ever necessary to adjust the friction, be *very* sure it is not too tight.

Questions on Planer Construction

1. What is the value of the planer in machine construction?

2. The bull wheel revolves much slower than the driving pulley. How do you explain this? Why is it necessary?

3. What is a rack? How is a rack used in moving the platen?

4. What is the purpose of having a quick return of the platen? How is it accomplished?

5. Why are the holes in the platen reamed?

6. How is the length of stroke changed?

7. The planer does not reverse at *exactly* the same point each stroke. How do you account for this?

8. What are the features of the housings that give them strength and rigidity?

9. How are the front surfaces of housings finished? Why?

10. How is the crossrail clamped to the housings? When is it clamped? When must it be loosened? Why?

11. What is the purpose of the saddle? What is the reason for having a gib between the saddle and the crossrail-bearing surfaces? When is the saddle-binding screw used?

12. What is the difference between the swivel graduations of the planer head and the graduations on the downfeed screw?

13. Why is it unnecessary to show by graduations the amount the apron is swiveled?

14. Downfeed may be accomplished by turning either one of two handles; where are these handles?

15. Explain briefly the general action of the belt-shifting mechanism.

16. In the planer, the feed operates during the time it takes to move the platen about 6 in. and not during the whole stroke. How do you explain this? Explain how the feed would operate if there were no stops on the friction device.

17. Explain briefly the action of the feed rack, feed gears, ratchet, and pawl.

18. How tight should the friction be adjusted? Give reason.

19. How is motion transmitted from the ratchet and pawl through the feed rod and four bevel gears to the downfeed screw?

20. How may the platen be stopped without stopping the driving belts? What is the purpose of the safety catch?

21. If the job is at all particular is it safe to assume the crossrail is parallel to the platen? That the head is set square?

22. How could you use parallels to set the crossrail parallel?

23. If suitable parallels were not available how could you use an indicator to test the setting of the crossrail? Why would it be advisable to clamp or block one end of the rail if an adjustment of the other end were necessary?

24. Arrange a tool up side down in the planer head and lightly clamp the frame of a micrometer to the tool, with the barrel projecting downward. Take a reading of the micrometer when the end of the barrel touches the platen (or a parallel on the platen) at each end of the crossrail. How much is the crossrail out of parallel?

25. If you should see a man tugging at a handle to move the planer head or the crossrail, what would you think? Give reason.

26. How much work does the feed friction have to do? How do you tighten the friction? How much?

CHAPTER VII

PLANER WORK

138. Introduction.—Planer work is especially important for several reasons: (1) It is, for the most part, the finishing of accurate surfaces on expensive pieces. (2) It calls for more than ordinary intelligence, ingenuity, confidence, and carefulness. (3) Because it demands mental effort and manual skill to an unusual degree, it is interesting. (4) It pays better than average.

Planer work as a whole involves a considerable knowledge of general machine-shop skills, like grinding and setting the cutting tools, judging speeds and feeds, measuring, etc. It involves the same sort of information as used in shaper work, for example, to get flat, square, angular, or irregular surfaces. Other similarities might be mentioned, but, in addition to all of these, planer work has its own special requirements of laying out, leveling, and clamping the work.

Like every other machine operation, planer work is easy enough if one knows how. At first, however, the expert planer hand had, somehow, to learn the fundamentals. In the the beginning he found it fairly difficult to level the work, and apply the clamps and stops mechanically right. He was probably a trifle nervous about the depth of cut and the feed, and, no doubt, fearful of a shoulder. But, because he studied and reasoned and worked intelligently, on one job after another, he gained knowledge and skill.

This chapter includes discussions of the several methods of holding work—the devices and tools used and how they are set and adjusted; the stresses that may bother, and how they are avoided, or their bad effects corrected, by the use of packing and shims, and with careful attention to leveling and proper

clamping. Two or three pages are given to the subject of laying out, which work is often so necessary in planer work. Then measuring and gauging are explained. It is these things, plus the tooling and handling of the machine, that constitute planer work.

It is quite probable that the student has already gained some knowledge of laying out work and of clamping principles, but a short review and added information will be helpful. Be sure to understand, thoroughly, planer work as discussed in

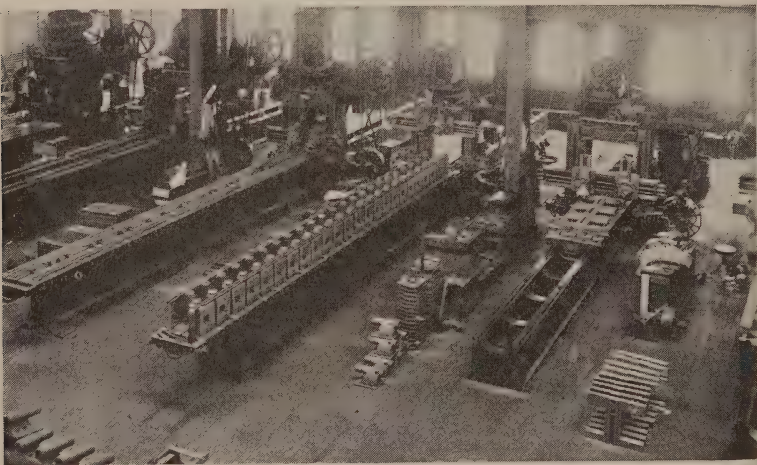


FIG. 139.—Planer work. (*Courtesy of The Hendey Machine Company.*)

this chapter. Reference is made to the similarity of planer and shaper work; there are many points in common. It has been noted again and again that learning about one machine helps in learning about another, but remember, the information in this chapter is of paramount importance in planer practice.

139. Methods of Holding Work.—A great variety of shapes and sizes of work may be machined in the planer, and of course this means that a variety of holding and clamping devices are necessary planer equipment.

Planer "furniture," in common with the work-holding appliances of any other machine tool, may be roughly divided into

two classes—general utility tools and special tools. In planer work as in other machine work, the need and value of the special tools and fixtures[1] is determined by the quantity of the work. That is, where a great many duplicate pieces are to be planed it is economy to make a fixture in which the work may be quickly set up, correctly aligned, suitably supported, and properly clamped. The fixture may be designed to hold a single piece or a dozen or more, depending on the size of the work.

On the other hand, this work, one piece or a dozen, could, no doubt, be held very well by means of general-utility furni-

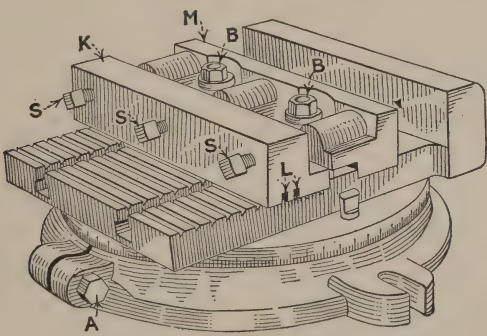


FIG. 140.—Planer vise or "chuck."

ture—clamps, stops, angle irons, strips, whichever seems best suited. Certainly one who can intelligently use the regular holding tools will have no trouble using a fixture.

140. The Planer Vise.—The planer vise, sometimes called the planer chuck, is very useful for holding many jobs that are too large or of such a shape as to be impracticable to machine in the shaper. Planer vises are made with plain or swivel bases. Figure 140 illustrates a swivel vise. By loosening the binding screw A (in some vises one and in others two) the body of the vise may be set in any desired position, the angle of the setting being indicated by graduations in degrees. A taper pin, with a squared head for easy removal, is sometimes provided exactly to locate the vise when the

[1] Definition of fixture, page 249.

jaws are either parallel or at right angles to the direction of the cut. One jaw of the vise is fixed, and T slots are provided in the body for clamping the movable jaw *M* by means of the two bolts *B*. The upper face of the body has cross slots to receive the thrust strips *L* held in the backing block *K* which are provided to keep the backing block from slipping after it is located. To fasten the work in the vise, place it against the solid jaw, move sliding jaw up to the work, and tighten the nuts *B* lightly; bring up backing block with thinner section partly under the movable jaw and the thrust strips in the slots; tighten the three setscrews *S* sufficiently tight to hold the work and then *tighten* the nuts *B*. Finally tap

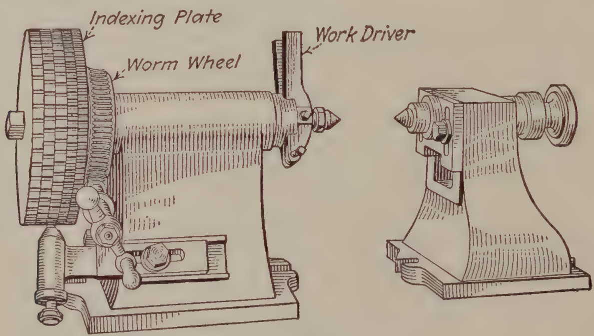


FIG. 141.—Planer centers.

the work to make sure it is seated properly. Vise-work operations in the planer and shaper are in principle exactly alike. The planer has the advantage of a longer cut. A piece much longer than the vise may be planed if a suitable support, a jack for example, is provided under each of the projecting ends.

141. The planer centers (Fig. 141) are comparatively little used as a means of holding work. Most jobs that require indexing can be more advantageously done in a milling machine. There are, however, many occasions in the building of special tools and machines when the planer centers offer the most expedient way or perhaps the only way of finishing a given flat surface or a given curved surface, or one or more

slots in an exact relation to a part already turned or in relation to a hole in which a mandrel may be inserted.

A suitable dog is fastened on the work or the mandrel and the tail is clamped in the slotted driver by a setscrew after the work is adjusted between the centers. The work may be adjusted for position by turning the handle which operates the worm and wormwheel and is held in this position by the index plunger. For some pieces it may be advisable to further secure or steady the work by blocks or jacks.

If it is desired to plane a curved surface, the tool is set "on center," a distance equal to the radius desired above center, and the work is "fed" for each cut by moving the worm handle a part of a turn.

The tailstock center is inserted in a block, adjustable vertically, for the purpose of planing tapered work.

142. Holding the Work on the Platen.—In ordinary planer practice but few pieces are held by any of the methods previously mentioned; by far the greater proportion of the work that is to be machined in the planer must be fastened more or less directly on the planer platen.

To be able to "set up" the average planer job intelligently the operator must know the tools used for holding and clamping and the principles of their application. For the best method of clamping he must often rely upon his ingenuity.

The success of any job that must be clamped to the table of any machine such as the shaper, drill press, boring mill, or milling machine; the faceplate of a lathe, or the platen of a planer, depends almost entirely on the manner in which it is clamped, that is, on the knowledge and resourcefulness of the operator. Efficient clamping looks simple enough, but it certainly calls for brains.

CLAMPING ACCESSORIES

143. Bolts.—The familiar squarehead bolt (Fig. 142) is largely used, and for ordinary clamping purposes is satisfactory. To place in position it must be pushed along the T slot from one end. The T-head bolt offers the advantage of being

quickly placed in position as shown. Simply drop the head lengthwise in the slot and turn to the right. This is especially convenient when clamping on the inside of castings which would otherwise have to be lifted over the bolt. Many prefer the tapped T head which is stronger and in the end probably more economical. If it is required to clamp inside of a casting, the stud may be removed and the head pushed along the slot under the casting to the desired position. Studs of various lengths may be used as needed, requiring only a comparatively small number of tapped heads.

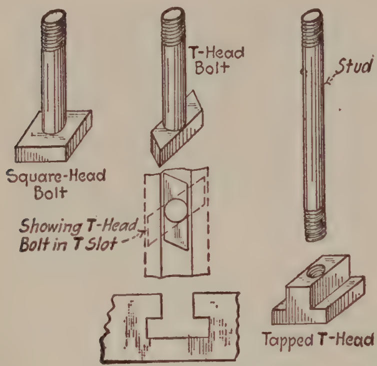


FIG. 142.—Bolts.

144. Clamps.—The *flat clamp* or "*strap*" (Fig. 143) is provided with a bolt hole (usually elongated) somewhat nearer the front end or work end. The front end is usually beveled as shown.

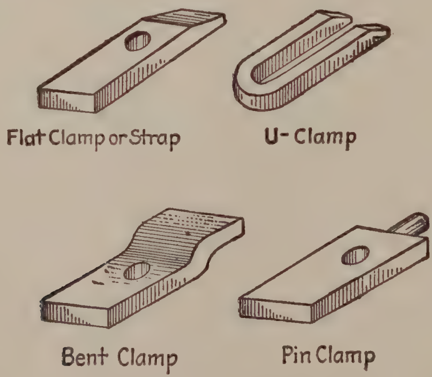


FIG. 143.—Clamps or "straps."

The *U clamp* may be removed from the bolt without removing the nut. It is also very convenient for purposes of adjustment.

The *Finger Clamp* or *Pin Clamp.*—Sometimes a piece of work may be of such proportions that it is inconvenient or impossible to clamp in the regular way and permit the top of the work to remain clear. In such a case it may be admissible to drill one or more holes in each end for the purpose of receiving the turned portion of the clamp. If a finger clamp is not available a short piece of round steel may be used; allow about ½ in. of the pin to project and apply a flat clamp.

The *bent clamp* is often useful when it is desired to bring the nut on the clamping bolt below the travel of the tool.

145. Clamping Blocks.—The block under the outer end of the clamp may consist of a piece of handy scrap metal of the

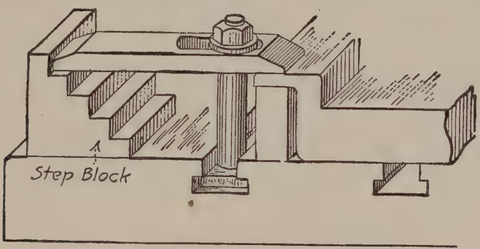


FIG. 144.—Shows use of step block.

required dimensions or if of considerable height suitable pieces of hardwood may be employed. Have the wood of sufficient cross section to give the needed stiffness and arrange under the clamp so that the pressure will be exerted *lengthwise of the grain* so it will not crush. Figure 144 shows a step block which is very useful. Both bases are finished and either may be used.

146. Shims.—A shim is a piece placed between the table and the work or for that matter between any two pieces or parts for purposes of adjustment or to give support. A shim may be rectangular or tapered slightly, and may be of metal, wood, or paper. Usually, however, a shim is considered as a thin piece of metal, while the heavier pieces are called "packing blocks."

147. Planer Jacks.—For leveling up work or for supporting projections under cutting pressure a jack is an invaluable tool.

Figure 145 illustrates a very convenient size. The jack *A* is $1\frac{1}{4}$ in. in diameter at the base and has a range from $2\frac{1}{4}$ to $3\frac{5}{8}$ in. Two extension bases *B* and *C* are provided to extend the range to $6\frac{1}{2}$ in. The base *E* is supplied for use when such a shape is desirable. The pointed screw *D* is provided to be used in place of the screw with the swivel cap in certain places where it may be needed, as in a corner.

148. Braces.—Sometimes a job is of such proportions, fairly high and with a comparatively small seating surface, that braces are necessary to assist against the tendency to tip under

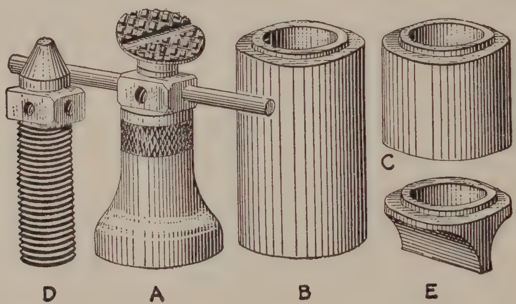


FIG. 145.—Planer jack. (*Courtesy of The L. S. Starrett Co.*)

the cutting pressure. Wooden braces arranged from the work to stops in the table are usually satisfactory.

If, however, a more substantial brace or perhaps an adjustable brace is desired, a piece of pipe of the length required may be provided between the jack *A* and the base *E* (Fig. 145), giving an excellent adjustable brace. A piece of pipe, with a washer, nut, and bolt or screw arranged in one end for the purpose of adjustment, makes a very satisfactory brace.

149. Planer Poppets, Stops, Toe Dogs.—*Planer poppets* may be made in either style *A* or *B* (Fig. 146). The hole is drilled and tapped about 10 deg. out of parallel with the platen to give the screw a certain downward thrust when in use. Style *B* may be made of round or square stock, as desired.

A *stop* is a piece against which the work is arranged, in order to resist the tendency of the work to move owing to the force of the cut. Oftentimes one or two *stops* will act as well as

half a dozen *extra clamps* on the work. A poppet made as shown at C with the screw set low and parallel with the platen is very satisfactory as a stop. Or a clamp securely tightened to the platen may be used.

Toe dogs (D, Fig. 146) used in connection with the poppets offer an excellent holding device, especially for thin work. To protect the planer table a piece of thin stock, for example, a washer, should be placed under the toe (see Fig. 147 also Fig. 149). A positive stop should nearly always be used

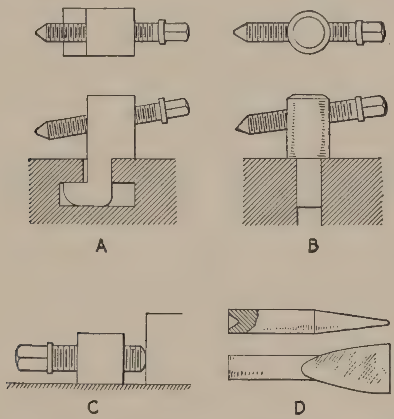


FIG. 146.—A and B, planer poppets; C, stop for work; D, toe dog.

when the work is held by toe dogs, and great care taken not to buckle the work by unduly tightening the poppet screws.

Suitable lengths of "pins," made, for example, of sections of discarded round files about ½ in. in diameter, are sometimes used instead of toe dogs. They are pointed similar to a center punch on one end to hold the work, and the other end is rounded to fit against a *cupped*-end poppet screw. If they are arranged to point slightly toward the stop, they will tend to hold the work snugly against the stop as well as down on the platen.

150. Planer Strips, V Blocks, Angle Plates (Fig. 147).—These are pieces of metal, usually cast iron, with a uniform cross section of the desired shape and size and of any conven-

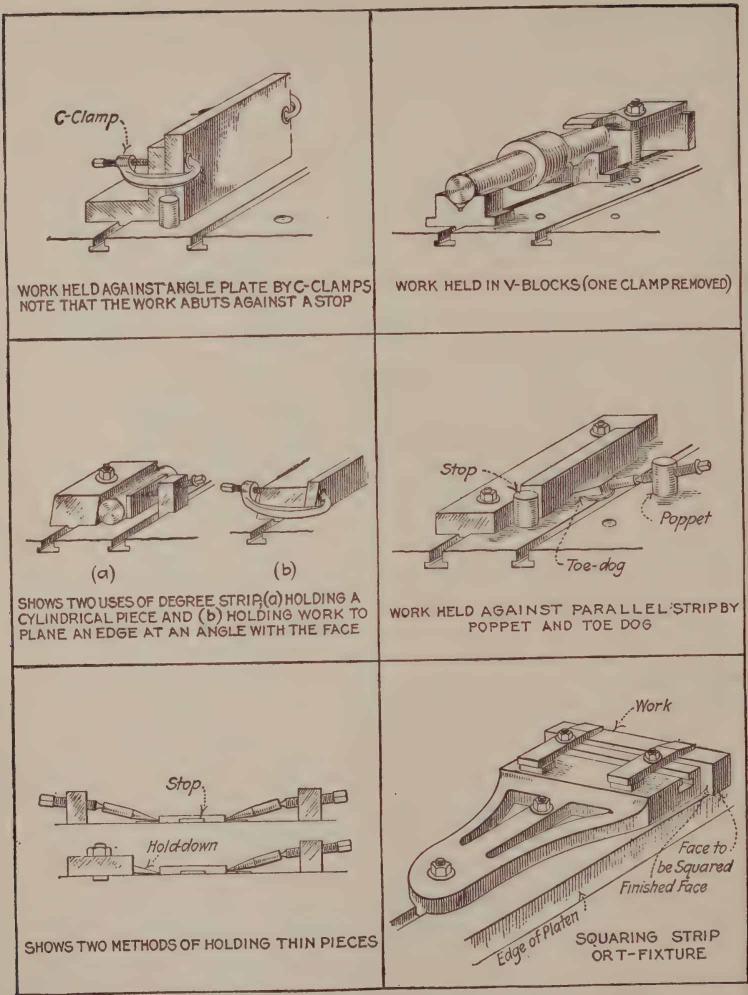


FIG. 147.—Typical planer setups. In any planer setup, the idea is to have the work neatly and securely clamped, a stop used if possible, and particular care taken not to spring any part of the work. Avoid using bolts that are too short or much too long. The surfaces of all strips, parallels, and fixtures must be clean and free from burrs. Take real care to have the setup *mechanically* right.

ient length. The base surface of each is tongued or provided with keys that fit the slots in the platen, and bolt holes or flanges are provided for the purpose of clamping. Two or more may be used for the longer work or when several short pieces are to be planed at one setting.

PRINCIPLES OF CLAMPING

What knowledge is necessary in order to produce planer work of satisfactory quality and quantity? What must one know to avoid inaccurate or spoiled work, to minimize the chances of accident to work or machine? In other words, what are the factors in planer work that make for skill? The answer may be stated very briefly: Handling the machine intelligently, knowing the tools to use, taking the cuts to advantage are necessary and important factors, but it is safe to say that 90 per cent of planer skill is in *knowing how to hold the work.*

151. Internal Stresses.—A very large proportion of planer work consists of machining castings, mostly iron castings, direct from the foundry.

When a casting is poured, the molten metal coming in contact with the surface of the mold chills quickly and forms a skin or "scale" which is much harder and more brittle than the inside. This uneven cooling and the fact that the thin sections of the casting cool more quickly than the heavier parts cause interior stresses. These stresses are held more or less in subjection by the scale, and when the scale is removed the casting gives or warps.

This is the reason why the roughing cuts should all be taken before any face is finished. This procedure is not always necessary but should be followed if practicable and must be followed if a certain degree of accuracy is desired. If extreme accuracy is required, the casting should be allowed to "season" between the roughing and finishing cuts.

152. External Stresses.—Practically all metals used in machine-shop practice—iron, steel, brass, aluminum, etc.—spring under pressure. If a piece is clamped in such a manner

that it is sprung or buckled while the cut is taken, when the pressure is released and the piece resumes its natural shape, the machined surface will be inaccurate.

For this reason it is very essential if the work does not seat perfectly that it be shimmed or blocked, *particularly under the clamps*, to avoid springing. Usually the sound of a light hammer blow, *before the clamps are applied*, will indicate whether

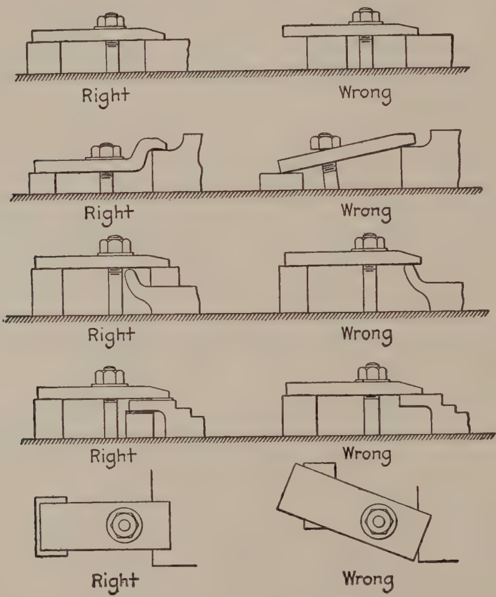


FIG. 148.—Right and wrong applications of clamps.

or not the piece is properly seated. A piece may be jacked, or braced, among other reasons to avoid the tendency to spring under the cutting action. Be careful, especially if screw action is used, not to set up the brace or jack too tight.

153. Placing the Clamps and Stops.—A clamp should be properly placed and the packing block under the clamp must be the correct height or the work may become loosened, with probable damage to both work and machine.

A very important point to be observed when clamping work is the position of the clamping bolt. It should be placed

as near the work as conditions will permit. (The reason is illustrated in Fig. 46, page 45.)

The clamp should have a firm seat on both the work and the clamping block. Packing under the outer end of the clamp should be at least high enough to bring the clamp parallel with the surface on which the work rests. It must never be lower or the clamp will only have contact on the edge of the work. It may be a trifle higher to insure against an edge contact, but if either too high or too low the bolt-

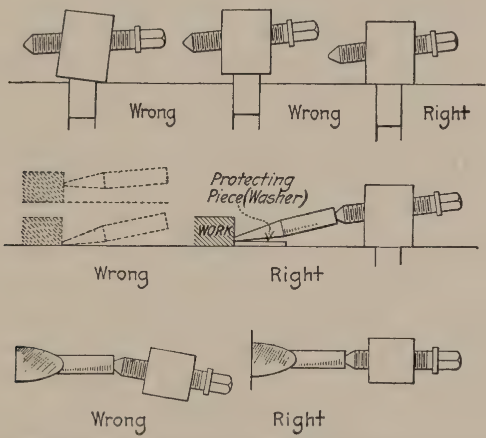


FIG. 149.—Right and wrong uses of poppets and toe dogs.

head contact in the T slot and the nut-and-washer contact on the clamp are faulty, and the clamping force correspondingly weak.

The clamp must not be placed over a part that will give or spring under pressure until suitable packing is placed under that part.

In Figs. 148 and 149 are illustrated right and wrong methods of using clamps, poppets, and toe dogs.

The work should be held in the machine in such a way that it will not move under the cutting pressure. In planer work, the thrust of the tool is mostly in a forward direction and comparatively little in a sidewise direction. It is nearly

always possible and advisable to use positive stops. Poppets may often be used, but if these are too high a clamp may be bolted to the table; if not high enough possibly an angle plate bolted to the table will do.

The first-class planer hand uses clamps and stops *when, where,* and *as* he should. As previously stated, this calls for brains. Size up the work to be planed, use *reasoning* when determining how best to hold it, place the stops, clamps, strips, poppets, toe dogs, whatever is necessary to hold the work, with careful attention to having them placed and adjusted as right as any one could do it. If one does this, the chances are that it is a good setup, and a good setup is often more than half the job.

154. Clamping Hints.—1. Do not depend on the accuracy of vise jaws, parallels, angle irons, etc., without testing them.

2. Do not put a clamp on a finished surface without a protecting piece.

3. It is very easy to score the table by sliding a rough casting across its surface. Put down protecting pieces of cardboard or similar material. Also do not fail to protect vise jaws, angle irons, parallels, etc., when clamping castings and forgings.

4. Many pieces are spoiled owing to carelessness in cleaning the parts against which the work seats, or is clamped. When a piece is clamped in a vise, or against an angle iron or similar tool, care must be taken to clean away all chips and dirt.

5. After a piece is clamped in a vise, tap lightly with a babbitt hammer to seat it. Do not tighten the vise again after seating the work as this is likely to lift the work from its seat.

6. When work is held on a table against an angle iron or similar piece, place tissue paper under each end of the work to determine if it is properly seated. Tap it lightly if necessary.

7. Use a stop against the work wherever convenient, and avoid unnecessary clamping.

8. It is very easy to buckle a thin piece, and great care must be taken when clamping such a piece in a vise, or when using hold-downs or toe dogs.

9. Form the habit of sighting over the top of the work under the crossrail, and along the sides next to the housings *after* clamping, to make sure everything is clear.

10. Use the proper-size solid wrench to avoid rounding the corners of the nuts.

11. The selection of the wrench, the way it is held and *controlled*, and the judgment used in the amount of force exerted, are indications of a mechanic's skill.

12. The thread of the bolt or nut should be oiled occasionally to save time and trouble.

13. Never use a nut without a washer.

14. Avoid, if possible, using bolts that are excessively long, and do not in any circumstances use a bolt too short, with only three or four threads catching in the nut.

15. Particular care should be taken to return clamps, bolts, and all other clamping accessories to the place where they belong. This is only fair to all concerned.

16. To plane several pieces (a "string") at one time no doubt saves a considerable amount of time in adjusting and measuring, and very frequently in the cutting operation. If many duplicate pieces are to be planed, a "string fixture" has many advantages in respect to saving time and labor.

155. Leveling.—As previously stated, most work comes to the planer in the shape of rough castings. Leveling is the process of setting up the casting in such a manner (1) that it will machine to size and to the best advantage, and (2) that it is supported at the proper points by blocks or shims or braces so that it will not buckle or spring under the clamping pressure.

In many cases if care is not taken in leveling in the setup, the casting will not clean to dimensions required. Sometimes even a simple casting, a plate for example, with apparently plenty of metal for machining, will be so badly warped that extra care must be taken when setting up for planing the first or working surface. It must be *leveled* with a surface gauge (Fig. 150) in such a way as to average the corners for height, with due consideration for later planing the other side.

It will possibly be necessary to shim under two corners, maybe three and possibly all four corners. In addition, shims will no doubt have to be placed under certain points where the clamps are to be applied, no matter what kind of clamping device is used. This is because the tremendous screw pressure of the bolt and nut will spring even a heavy casting unless it is solidly supported under the clamp.

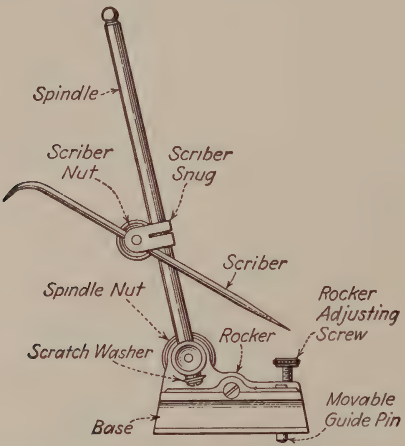


FIG. 150.—Surface gauge. This is an invaluable tool in planer work for scribing lines and for leveling either a surface or a line. (*Courtesy of The L. S. Starrett Company.*)

156. Laying Out.[1]—The leveling of the usual casting means only proper blocking, shimming, and clamping, but averaging the surfaces of an intricate casting, or one having surfaces likely for any reason to be scant, calls for a preliminary layout. Usually this work is done before the casting comes to the planer, but quite often the planer hand must do it.

Every casting, but more particularly the irregular-shaped piece, has a base and possibly a side "working surface" that must be established before cuts are taken. The planer hand must know *how much stock* to take off these surfaces and *where*

[1] For further information concerning layout work see page 40 in this book and also Chap. XIII, Part I.

it must be removed. For example, it may be that $\frac{3}{16}$ in. must be taken off one part of the base and only the scale from another part in order that the casting will "clean up," that is, every other surface that must be planed will have stock enough to finish. If other surfaces must be planed to finish a certain distance from a side or an edge, then the working side or edge must be established and the dimensions checked to make sure all surfaces will clean. In other words, if the machinist sets the casting without realizing that a certain surface, being low or "scant," should be "favored" and proceeds to take an even cut from the working surface, then the low part, in a later setup, will not clean, and the job is spoiled.

To check the dimensions from the base or edge, the work is tentatively leveled on a plate or table, often on the planer platen, and a layout is usually made. This layout is, in a sense, the measuring of a casting; lines are drawn on the chalked surfaces to verify on the casting the dimensions given on the drawing. The layout does not usually have to be especially accurate; the lines are merely check lines.

The tools used are various blocks and shims to use in leveling, parallels of the sizes required, one or more surface gauges, a combination square, scales, a scriber, possibly a bevel protractor. For scribing distances, dividers and trammel points are often used. To whiten the surface, chalk may be rubbed on, or a mixture of chalk and water (whiting) may be applied with a brush.

Set up the casting to have it appear about right, shimming where necessary, that is, make a tentative leveling, and with a surface gauge or scale check any surface that seems to be low. If releveling is necessary, shim the work to bring the low surfaces high enough to clean. Sometimes, when scribing the lines, it will be found that a surface is undersize, which means that the casting will have to be leveled again and a new layout made. This is much better than finding the low surface after several cuts have been made and the work possibly spoiled.

Base lines or, if more convenient, lines that are parallel to the base should be scribed. These are used when setting up for planing the base.

After the layout is complete, the work is usually leveled to the base-surface layout, clamped, and the base planed. When the remaining surfaces are planed, the machinist does not, ordinarily, plane to the lines; the surfaces are *measured* or *gauged* from the base, or from another finished surface, as the case may be.

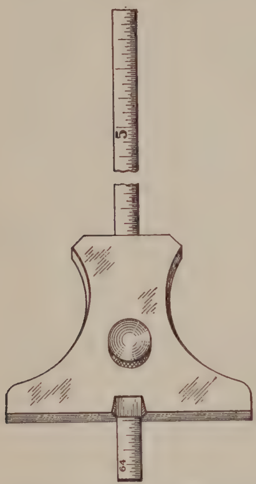


FIG. 151.—Depth gauge, used for measuring shoulders, depth of slots, etc. (*Courtesy of The L. S. Starrett Company.*)

157. Measuring and Gauging.—The test of a plane surface is, first its flatness, second its relation to another surface—its squareness or its other angularity to this surface, or its distance from another surface. The best method of testing for flatness is by means of a suitable straight edge placed on the work, or by turning the work over and placing the surface to be tested on a surface known to be flat. In the latter case, the platen of the planer is frequently used. When the surface is flat, there is no "rock" of the work on the platen or no "hollow sound" under a light blow given anywhere on the work.

If a straight edge is used, it should be tried in several positions on the surface with tissue-paper feelers[1] to determine the straightness and flatness of the surface. Feelers may often be used in a similar way between the corners of the work and the surface plate or planer platen.

Tissue-paper feelers are frequently used with a square to test if a surface is at right angles with another surface and may be used with a bevel protracter to test the accuracy of an angular cut other than 90 deg.

[1] If a straightedge is placed on a surface with narrow pieces of tissue paper between, say one at each end and one in the middle, and any one of them pulls easier than another, it indicates that the surface is not flat.

For measuring or gauging the height of a surface, direct scale measurement may be good enough, or a surface gauge set to a scale. For measuring the height of a shoulder a size block (Fig. 119) or a depth gauge (Fig. 151) is useful. A combination square may be used to test the distance from one surface to another either horizontally or vertically. When a con-

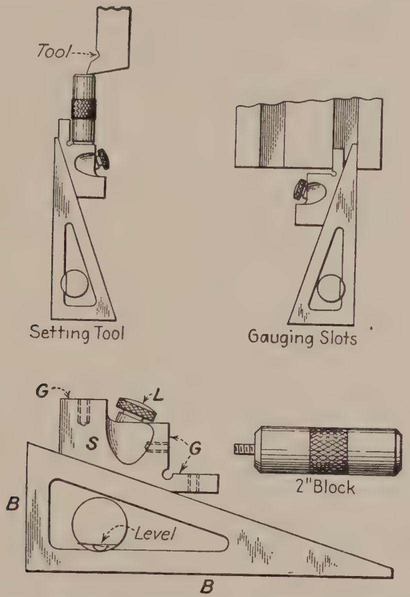


FIG. 152.—Planer gauge. This tool is provided with two bases *B*, an adjustable slide *S* locked by *L*, three gauging surfaces *G* which may be extended by the use of various lengths of extension blocks. Thus it has a wide range of sizes that may be set by micrometer measurement to gauge the width of slots, shoulder distances or like dimensions, and to set the edge of the cutting tool either a vertical or horizontal distance from a base or shoulder. (*Courtesy of The L. S. Starrett Company.*)

siderable number of pieces are to be planed with angular cuts, shoulder cuts, etc., it is advisable to have tool-setting gauges and work-testing gauges as part of the equipment for that job. The planer gauge shown in Fig. 152 is very useful.

158. Planer Cutting Tools.—The generally used planer tools are substantially like shaper tools for like operations, the only difference being the size. Descriptions of these tools

are given, beginning page 98. Attention is called also to Fig. 153 illustrating shapes recommended by a prominent planer manufacturer. Note the tools in Fig. 154 and particularly the side tool *c*. Planer tools with negative rake have the impact of the cut some distance behind the nose, and are less likely to break the tip.

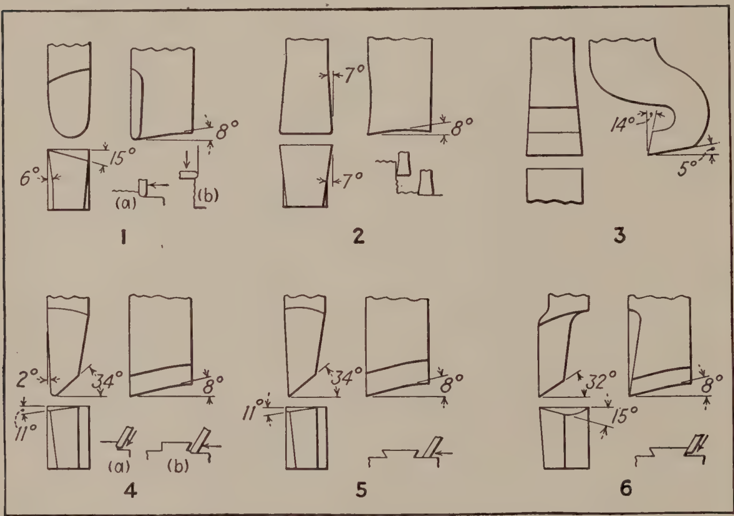


FIG. 153.—Planer tools recommended by The G. A. Gray Company.

1. *Round-nose roughing tool.* Made either right-hand or left-hand. May be used for practically all roughing cuts in cast iron, either horizontal or vertical as shown in (*a*) and (*b*). For cutting steel a side rake of about 20 deg. is given.

2. *Square-nose tool* for cast iron. For roughing and finishing horizontal and vertical cuts to a square shoulder.

3. *Gooseneck tool,* for finishing any metal. Oilstone the cutting edge, and set exactly parallel with the surface to be planed.

4. *Dovetail roughing tool* for cast iron. Made right-hand or left-hand. The corner is slightly rounded to avoid breakdown in a heavy cut. May be fed down as in (*a*) or horizontally as in (*b*). Followed by 5 and 6.

5. *Dovetail horizontal-finishing tool.* Made right-hand or left-hand. Feed towards the dovetail corner.

6. *Dovetail side-cutting finishing tool.* Made right-hand or left-hand. Use a coarse feed with a light cut.

159. Setting the Tool.—To accommodate different heights of work the crossrail clamping device is loosened and the crossrail adjusted vertically (see 1, page 145). If there is doubt that the rail is parallel, test with indicator (page 148).

If the crossrail is *set too low,* so that the work or holding tools will not pass under (clear) during the cut, an accident

is sure to happen. If the rail is *set too high*, it means that either the toolhead slide, or the tool, or both, will project (overhang) too much, in order to have the tool reach the work. This will cause the tool to chatter on a light cut, and dig in on a

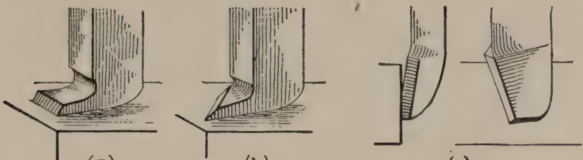


FIG. 154.—Tools for finishing cast iron. (*a*), Shovel-nose; (*b*), shovel-nose ground for shear cut; (*c*), front and side views of side tool.

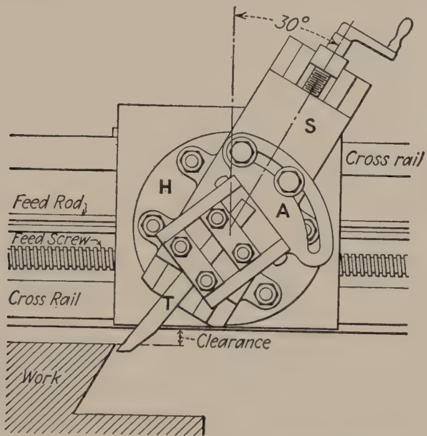


FIG. 155.—Crossrail toolhead set for 30 deg. angular cut, with the top of the apron *A* set over in a direction away from the surface being cut. (Rule, page 120.) Note that the slide *S* is well up at the start of the cut in order not to overhang too much at the bottom of the cut. Note also the *clearance* between the crossrail and the work. In this job the tool *T* must project far enough to reach the bottom of the cut.

heavier cut. Ordinarily an inch or two clearance above the highest part of the work or work holder is satisfactory. Note the clearance in Fig. 155.

When setting the planer tool, be certain the clearance under the crossrail is all right, *enough and not too much*. Ordinarily there will be no overhang of the toolhead slide. For most

horizontal cuts the tool is held perpendicularly; if then, by any chance it moves in the tool block, it will not cut deeper into the work. Catch the tool fairly short, for rigidity, and *always* clamp it tight.

When planing an angular cut, or a vertical cut using the crossrail head, it is best to have the slide well up at the start of the cut in order not to have it project too far as the tool reaches the bottom of the cut (see Fig. 155).

When it is necessary to have the tool overhang an unusual amount, a correspondingly light cut must be taken.

160. Cutting Speed, Depth of Cut, and Feed.—In the planer as in other machines, these must be considered. In the planer there is less need than in other machines for a variety of speeds, for the reason that the only variations to be considered are the kind of cutting tool used and the material being cut. A moment's thought will show that the speed of the planer need not be changed for different lengths of work, as in the shaper, or for different sizes of cutting tools, as in the drill press or milling machine.

In many shops the planer is used altogether on the same class of materials and has but one speed forward, with a quicker return. However, four-speed countershafts and variators (Fig. 135) are not uncommon. They usually give cutting speeds of around 20 ft., 30 ft., 40 ft., and 50 ft. per min., and 100 ft. per min. return. (See Table 3, page 478.) The hydraulic planers have a continuous range from 0 ft. to 80 ft. per min. or more forward, and up to 150 ft. per min. return.

The planer is regarded as a rugged machine, capable of holding heavy pieces and taking heavy cuts. The very nature of the machine, carrying the heavy load, gives the impression of power. But while in theory the cutting speed, feed, and depth of cut are governed by the same conditions as in the lathe, shaper, or milling machine, it is probable that the planer averages much slower speeds than any other machine in the shop, for a number of reasons. For example: the nature of the machine, with its heavy reciprocating platen and load; the way most of the work must be held, such as irregular shapes held

by clamps and braces; and the kind of cut, that is, machining very accurate surfaces on expensive castings. If the planer is equipped with speed changes, select the nearest speed suitable for the cutting tool and the material to be planed with due consideration for the kind of setup and the nature of the operation.

The depth of the cut and the feed are also always governed by conditions. It is impossible to give a rule. The suggestions given on page 104 should prove helpful; also see paragraphs 162 and 163. Read these carefully, be sure to understand the importance of your judgment. Remember it is thinking through each problem that counts for a satisfactory job and continued progress.

161. Starting the Cut—General Precautions.—1. Step to the end of the platen and sight under the crossrail and between the housings to be sure of *clearance* of all parts of the work and all holding tools.

2. See that the dogs are set for the proper length of stroke; remember the feed should be completed before the tool begins to cut.

3. In addition to the gibs for adjusting the downfeed slide on the toolhead, and the saddle bearing on the rail, there are *binding screws* that serve to tighten the slide or the saddle to make either one more rigid when its particular feed is being used. Do not fail to see that these binder screws are loosened in one case, tightened in the other, depending upon which feed is to be used.

4. The edge of the work is not always straight, and to avoid the chance of jamming the tool, or possibly spoiling the work, by too heavy a chip at either end of the cut, run the machine the whole length of the stroke before taking a cut, to judge how far to feed the tool in, by hand, before throwing in the power feed.

5. Remove the handle from the feed screw or feed rod when the power feed is being used.

6. Keep your hands away from the tool, and from the work near the tool, while the machine is running.

7. Never use a wrench on any part of the machine, or on any clamp, while the machine is running.

8. Do not brush off the chips when the machine is running, and never brush them in the direction of the ways. Cast iron scale is hard and gritty; brushing it into the ways will soon destroy the accuracy of these bearings.

162. The Roughing Cut.—When taking a roughing cut, the combination of feed and depth should be as great as the nature of the work, the manner in which the work is held, the kind of cutting tool used, and the strength of the machine will permit. When roughing cast iron, care must be taken that the tool does not rub on the scale during any part of the cut. Also in roughing cast iron, in order not to break the corner below the surface at the finish of the cut and thus leave a ragged edge, this corner should be chipped or filed to a bevel of about 45 deg. and to an amount about equal to the depth of the cut.

When roughing, the feeding movement should not take place at the end of the cut because the dragging of the tool on the scale will tend to injure the cutting edge. It should take place at the start of the forward stroke and *before the tool enters the metal*, otherwise the feeding mechanism is unduly strained. Usually allow about 6 in.

163. The Finishing Cut.—Usually a better finish is produced on *steel* with a fairly light chip and a fine feed. The commercial finish on *cast iron* is produced by using a wide square-nose tool with a light chip (0.002 to 0.005 in.) and a feed of ½ in. or more depending on the size of the work (see page 118). That is, a better finish is obtained on cast-iron work by taking a fairly wide scraping cut than is obtained by taking a deeper cut with a finer feed. This is true on horizontal, vertical or bevel surfaces. If the tool tends to chatter, the fault may often be remedied and the chatter marks removed by using a tool which will give a shear cut. In Fig. 154 is illustrated a shovel-nose tool for a horizontal surface and a side tool for a vertical surface, each so made as to give a shear cut.

164. A Typical Elementary Planer Job.—Directions for planing a bench plate or surface plate:

THE HORIZONTAL CUT

1. **Place the casting on the platen, and level it.**
   a. If the casting is likely to score the platen when moved around, use heavy cardboard or old belting underneath until the plate is in position.
   b. Place one or two stops (paragraph 149).
   c. Remove the protecting pieces and level the work (paragraph 155) using shims where necessary (paragraph 146).
   d. Tap the work, on the corners especially, and if it sounds hollow it may need further shimming.
2. **Place the poppets and toe dogs and tighten the poppet screws.**
   a. Depending on the width of the plate and the platen, either kind of poppet *A* or *B* (Fig. 146) may be used, possibly *A* on one side and *B* on the other.
   b. Place poppets about 6 or 8 in. apart, usually along the sides and not on the ends. Refer to Fig. 149.
   c. If lack of room prevents using poppets on the sides, they may be used on the ends, provided care is taken when the cut is being made that the tool cannot hit a poppet at either end of the stroke.
   d. Use a washer under each toe dog, and try to use reasonable judgment when tightening the poppet screws.
3. **Select the tool (paragraph 158).**
   If necessary to sharpen the tool, be careful of the front clearance—give it enough, but not too much. Refer to Fig. 90, page 98.
4. **Set the tool (paragraph 159).**
   a. If necessary, loosen the clamps and adjust the height of the cross-rail until it is 2 or 3 in. above the work. For accuracy refer to paragraph 129.
   b. Let the tool project 2 or 3 in. from the tool post, set it about perpendicular, and clamp it tight.
5. **Set the dogs for the length of stroke.**
   Arrange to have the feed take place before the tool begins to cut (paragraph 162).
6. **With a chisel or an old file, bevel the edge of the work a little to prevent a ragged corner.**
7. **Bring the tool a little past the edge of the work nearest you and lower it for the proper depth of cut.**
   On account of internal stresses (page 171) and consequent warping of the work, do not remove more than is necessary to get under the scale, otherwise you may not have enough thickness to finish to size.
8. **Arrange for the amount of feed desired.**

9. **Sight along both sides and over the top of the work (hint 1, paragraph 161).**
10. **With the consent of the foreman or instructor you are ready to proceed.**
11. **When one side of the plate is rough-planed it is turned over, carefully shimmed, and the other side roughed.**

    It may be necessary to take another roughing cut over the first surface before the edges are roughed in order to make this surface nearer flat and the plate nearer to the thickness required.

THE VERTICAL CUT

12. **The plate should project about ½ in. over the edge of the platen so that the down cutting tool cannot cut into the platen.**
13. **Be sure the swivel head is set on zero.**
14. **Set the apron (top of apron in a direction away from the surface to be cut, paragraph 105, page 120).**
15. **Set the tool.**
    a. Tools shown (2) and (3), Fig. 92, page, 100 also (1), Fig. 93.
    b. Have the toolslide moved fairly high up on the head so that it may be fed down a considerable distance without projecting too far below the head (Fig. 155).
    c. Bring the tool over the edge to be cut in position to take the roughing cut.
    d. Tighten the saddle-binder screw.
16. **Set the power downfeed.**
    a. First try the hand feed to be sure the slide is nicely adjusted.
    b. Probably three or four teeth will be sufficient for beginning. If later it seems too slow get your instructor's permission to increase the amount of feed.
17. **Before starting the cut, have the setup inspected.**

FINISHING CUTS

18. **Read paragraph 163, also last part of paragraph 103.**
19. **Having the work and the machine already set for the downfeed cut, you will probably finish the edges first.**
    a. The side tool (Fig. 154) may be used or the tool shown in (1) or (2) *b*, Fig. 93, with a tool bit ground to present a flat surface is very satisfactory.
    b. Be sure the toolhead is set exactly vertical.
    c. When one edge is finished, set it square with the edge of the planer platen and plane the next edge.
20. **Finish the horizontal surfaces.**
    a. Take great care when clamping the work (see paragraph 152).
    b. Tool used, Fig. 154, page 181, or Fig. 110, page 119.

165. Similarity of Shaper Work and Planer Work.—The similarity of the shaper and planer with regard to several of the details of construction, many of the methods of holding the work, most of the operations, and consequently the cutting tools used, serves to make a knowledge of the one a very great help in understanding the other.

Descriptions and explanations of many of the operations common to both planer and shaper have been given in Chap. V and will not be repeated here. Substantially the whole of Chap. V is as applicable to planer work as it is to shaper work. It is suggested, therefore, that the student who is not already familiar with shaper work as therein outlined refer to that chapter in connection with his planer work.

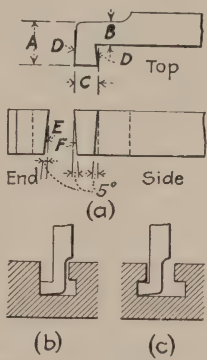


Fig. 156.—Tools for planing T slots.

166. Memoranda.—**Planing horizontal surfaces, vertical surfaces, rectangular pieces, angular or bevel surfaces, slots, tongues, grooves, keyways, keyseats, and dovetails,** has been described in the chapter on shaper work beginning page 98. Consult the index for the particular page.

167. Planing T Slots; Use of Tool Lifter. Figure 156 illustrates a tool for planing T slots. Two tools (right-hand and left-hand) are needed. The top face is flat (no rake), the cutting edge C is given clearance of about 5 deg. on the front E, sides F, and also from the front, as shown at D. As will be observed in parts b and c, which show, respectively, the start and finish of the cut, the width of the tool A cannot be greater than the width of the original slot (see b), and the width of the neck B must be narrow enough to permit the tool to cut its share of the T slot.

Many T slots in the smaller tables, fixtures, etc., are milled, but in the larger castings they are planed. A slot somewhat narrower than the finished size is planed to the depth required with sides parallel. The lower part of this slot is then widened with the T-slot tools, first one side and then the other as illustrated in b and c, Fig. 156, after which the original slot

is carefully planed to exact width. When planing a T slot, it is necessary to lift the tool out of the slot before the return stroke, or *to block it so it cannot lift.* Otherwise the tool will tend to lift against the shoulder and will rub so hard as to spoil the work and break the tool. In order to obviate the necessity of lifting the tool by hand each time, a tool lifter, (Fig. 157), may be used. There are a number of kinds of tool lifters, but a hasp or hinge fastened back of the tool as shown works very well. Sometimes an undercut on the edge of a piece of work is advisable. Such a cut may be made in the same manner as the T slot is cut. Further, the use of the tool lifter is frequently made when taking a finishing cut over

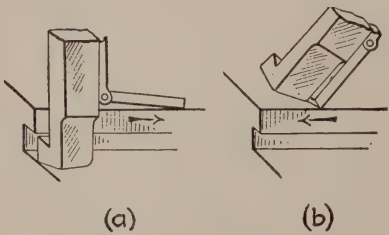


FIG. 157.—Shows tool lifter; (*a*), cutting stroke, (*b*), return stroke.

a large surface as it prevents the rubbing of the tool on the work and serves to prolong the life of the cutting edge.

Questions on Planer Work, I

1. What do you understand by the term "fixture" in machine work? What is the value of a planer fixture?

2. Explain in detail the operation of gripping work in a planer vise? How is the movable jaw held down? When is it fastened down hard? How is it backed up?

3. What advantage has a T-head bolt over a square-head bolt?

4. What is the advantage of the tapped T head?

5. What, in your judgment, is the use of a washer?

6. Describe briefly four kinds of clamps used in holding planer work.

7. What is the difference between "blocking" and "shimming?"

8. What is the advantage of a step block? How would you make a step block with four steps giving eight different heights?

9. Is the height of the block under the clamp an important feature of clamping? Give reason.

10. Is the position of the clamping bolt in relation to the work of any particular importance? Give reason.

11. When is a jack used in setting up a planer job? What precaution should be observed when using a jack?

12. When clamping work down on the platen, what precautions should be taken to avoid springing it?

13. How may a comparatively thin piece be held on the platen and the whole top surface planed at one setting?

14. What is the real purpose of a "stop" for the work?

15. In what respect is the "toe dog" like the hold-down or gripper?

16. Manufacturers of high-grade machines take a roughing cut on tables, beds, frames, etc., and then pile them in the yard for two or three months, possibly longer. What is the reason for this?

17. Why is it usually advisable to take all of the roughing cuts before taking any finishing cut?

18. What do you understand by the term "leveling" in planer work?

19. State three different uses of the surface gauge in planer work.

20. Frequently it is necessary to find the low spot on a surface to be planed and then set the tool to get under the scale the first cut. What gauge would you use for finding the low spot? For setting the tool?

21. How do the statements in paragraph 85, page 102, apply to the planer?

Questions on Planer Work, II

(For information see Chap. V beginning page 98)

1. What is the difference between a right-hand and a left-hand planer tool?

2. What is the effect of too much clearance on a tool?

3. How do you account for the tendency to grind too much clearance? What is the remedy?

4. What is negative rake? Explain the disadvantage of trying to cut with an edge having negative rake.

5. What do you understand by a shear cut?

6. Is Fig. 92 a chart of forged planer tools?

7. How do you reason the proper feed and a suitable depth of cut for a given planer job?

8. What are some of the reasons against running the toolhead slide down too far?

9. Why is the apron set over when planing a vertical or an angular surface?

10. What is the rule for setting the apron when taking a vertical or an angular cut?

11. How do you prevent the breaking of the edge at the end of the cut?

12. How do you oilstone the cutting edge of a square-nose tool?

THE MILLING MACHINE

CHAPTER VIII

MILLING-MACHINE CONSTRUCTION

168. Introduction.—Milling machines may be described as the class of machine tools in which the metal is removed by causing the work to be fed against a revolving cutting tool called the milling cutter, which has one or more (usually several) cutting edges. There are several ways of holding the milling cutter, which rotates with the machine spindle. It may be bolted directly to the nose of the spindle, or mounted on an arbor, the taper shank of which fits the taper hole in the spindle, or held in a collet or other adapter which fits the spindle. These will be discussed presently.

In all milling machines, cutters of a wide range of shapes and sizes may be used, and provision is made for changing the spindle speeds to accommodate cutters of various diameters, and suitable automatic feeds for the worktable are provided in all except the small (hand) milling machines.

The milling cutter may be made in almost any desired shape, and may be sharpened without destroying its shape. Several cutters may be mounted together on the spindle to machine several surfaces at the same time. These features in connection with the methods available of holding the cutter and the work permit of a variety of operations that make the milling machine one of the greatest factors in rapid production of duplicate parts, as well as one of the most valuable machines in the general machine shop.

It seems quite proper to differentiate between *factory-production* milling, and *machine-shop* milling—that is, tool- or modelmaking or maintenance work—in much the same

way that production turret-lathe work is differentiated from run-of-shop lathe work. The designing and making of the tools and fixtures for production milling, the setting of the machine, and the supervision of the work, is done by experts who have learned the principles and methods of milling. The production work is done by an operator who has only to know how to load and unload the machine.

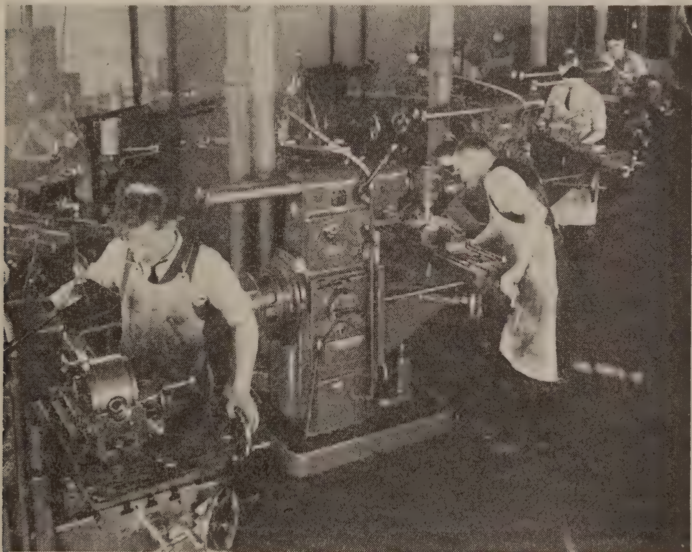


FIG. 158.—A group of milling machines in a toolmaking department. (*Courtesy of The Taft-Pierce Manufacturing Company.*)

Some of the production machines are highly efficient as to quality and quantity of output, their adaptability, and the ease in handling. Most of these machines, in various kinds and sizes, are now automatic or semiautomatic. This means, in the fully automatic, for example, that the table feeds may be set for automatic *rapid power traverse*, either direction, for return of table to starting position; for *intermittent* rapid-traverse and cutting feed, as when the surface machined is not continuous; for automatic reverse at each end of the cut, reversing at one end and stopping at the other, or stopping at

both ends; that *variable feeds*, for intermediate light or heavier cuts, are automatically controlled.

It is not the purpose of this book to discuss these machines or their production work.[1] They are mentioned here as examples of special and special-purpose machines which are all developments of machine-tool units provided with mechanical, electrical, or hydraulic control.

For the beginner in the machinist's trade, the most interesting and profitable experience is obtained by study and practice of the various operations on the standard machine. The principles of cutting tools, cutting speeds and feeds, holding the work and the cutter, adjustments, measurements, etc., apply to any type or size of machine.

Milling work offers all kinds of jobs from the meanest drudgery in the factory to the most particular and interesting work in the machine shop. Of all the machine-shop tools, only the lathe is comparable to the milling machine in the variety of operations. Most boys have to begin with the simple jobs on any machine, but the ambitious boy who is determined to learn will soon be too valuable to remain with the drudges. Running the milling machine intelligently involves a considerable knowledge of the following things:

1. The construction of the machine, that is, the names and uses of the parts, the location of the oil holes, the operations of the speed and feed mechanisms, and the various adjustments.
2. The construction, use, and value of the various attachments and accessories.
3. The cutters, their names and uses, how they are properly held in the machine, and how they are sharpened.
4. The efficient speeds and feeds for various kinds of work.
5. The methods of holding the work.
6. The setup that is mechanically right.

[1] For information about production milling, see *Practical Treatise on Milling*, Brown & Sharpe Manufacturing Co., Providence, R. I., and *A Treatise on Milling and Milling Machines*, Cincinnati Milling Machine Co., Cincinnati, Ohio.

7. The ever-present need for carefulness—*safety first*—around a revolving milling cutter.

It is suggested that the student read through this chapter and the next, to get the general idea of the machine and of the cutting and holding tools used, then go back and study the subjects in detail. Some parts will, of course, require more study than others; the purpose is to get such knowledge and understanding as will help in doing the milling job. Start with the idea that this machine with its great possibilities is

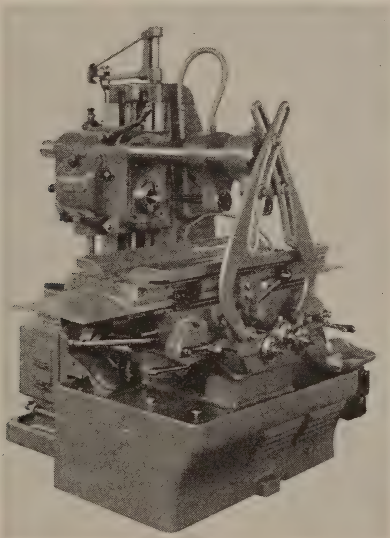


Fig. 159.—Bed-type plain milling machine. (*Courtesy of Brown & Sharpe Manufacturing Company.*)

simple enough, in any of its operations, if one understands the few fundamental principles.

169. Types of Milling Machines.—There are two distinct types of milling machines, the bed type which has a vertical adjustment of the spindle, and the column and knee type, which has a vertical adjustment of the worktable. Each type is made in many modifications and several sizes. The adjustable-spindle machine with its solid worktable base is no doubt more rigid for a given size than a machine with the

adjustable support for the worktable. However, these machines are not nearly so easily and quickly adjusted nor so adaptable for a variety of work as the machines having the adjustable-worktable support.

170. The Bed Type.—The original milling machine was of the type having a vertical adjustment of the spindle. The natural development has produced machines of this same general type in a wide range of sizes, and of great power and

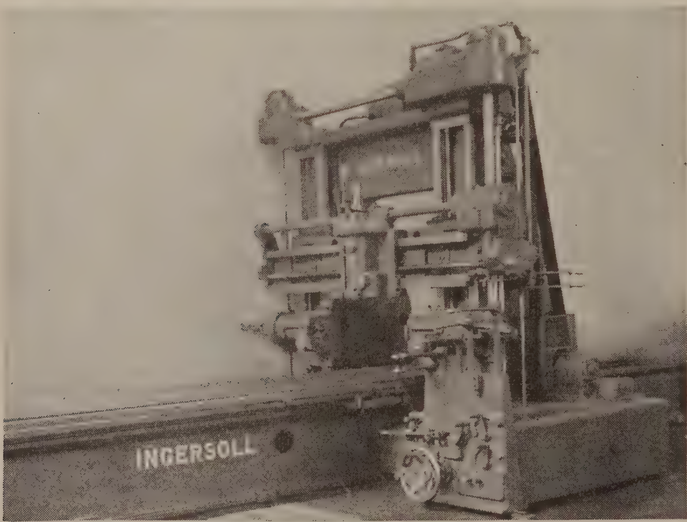


FIG. 160.—Planer-type milling machine. (*Courtesy of The Ingersoll Milling Machine Company.*)

rigidity. Also the increased flexibility and ease of operation are notable. The cutters, of carbon steel, of high-speed steel, or tipped with the new carbides, are made in a variety of kinds and sizes that gives a cutter for every purpose.

All of the bed type are more particularly *manufacturing* machines. They are used in milling a large number of duplicate pieces. Sometimes an unskilled man or boy can operate several machines after they have been "set up" by a skilled mechanic. That is, after the machinist has made the adjustments to take the desired cuts, the operator can remove from

one machine a piece that has been milled, and put in the next piece, while the other machines are running. Figures 159 and 160 show two kinds of adjustable-spindle milling machines designed especially for manufacturing purposes.

171. The Profiling Machine.—This machine (Fig. 161) is practically a milling machine of the adjustable-spindle type with the spindle held in a vertical position. The special

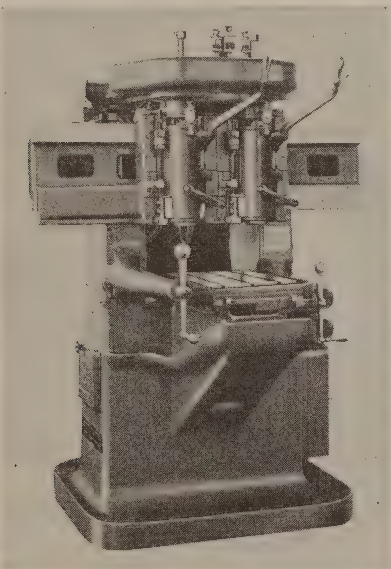


FIG. 161.—Profiling machine. (*Courtesy of Pratt & Whitney Company.*)

characteristic of the profiler is the guiding of the cutter, by means of a guide pin or "former pin," which is held against, and follows, the outline or *profile* on a template or guide block. The guide pin is fixed in relation to the cutter, and the template and work are fastened to the worktable in exact relation to each other; thus if the guide pin follows a predetermined profile, straight or curved, on the template, the cutter will cut the given profile on the work. Also, if horizontal surfaces in different planes are to be finished, as, for example, bosses of different heights on a casting, a guide block with the required

steps, exact distances one above the other, may be used to guide the end mill. The profiler is used in the making of small parts of irregular shape, as in the manufacture of guns, sewing machines, etc.

The cutter is held in the spindle by a drawbar. Several spindle speeds are available for different sizes of cutters and different materials.

The spindle and the guide-pin holder are carried in a vertical slide on the head, which is, itself, carried on a sliding surface on the crossrail of the machine. The *spindle slide* may be moved by a lever vertically through 4½ in. Positive vertical adjustable stops are provided, each having a dial graduated to read in thousandths of an inch. The spindle slide may be locked in any desired position.

The *head slide* is moved on the crossrail by a lever at the right hand of the operator through a rack and pinion. The *table* may be moved at right angles to the spindlehead slide by a lever at the left. It rides on ways and is gibbed ("strapped") to prevent any tendency to rise.

The table is controlled by the operator's left hand, and the head slide on the crossrail by his right hand, thus keeping the guide pin against the template as it moves along the guiding edge. For the cuts in different horizontal planes, the spindle is locked by a suitable lever exactly in place, as indicated by positioning the guide pin on the guide block.

The figure shows a two-spindle machine. By means of two spindles a roughing and finishing cut may be taken in one setting of the piece.

172. Milling Machines Having Vertical Adjustment of Worktable.—A large proportion of milling machines are of the type having the worktable adjustable for height. The saddle on which the worktable rests is supported on a knee which may be moved vertically on a finished face on the front of the column. The knee may be rigidly clamped in any desired position. This type of machine is classified as to kind as: *universal, plain, hand,* and *vertical.*

The Universal Milling Machine (Fig. 166).—The universal milling machine was invented in 1862 by Joseph R. Brown, one of the founders of the Brown & Sharpe Manufacturing Co. It is so constructed that the table may be swiveled to a considerable angle in a horizontal plane to permit of milling spiral (twisted) grooves such as are cut in twist drills, spiral mills, etc.

FIG. 162.—A group of milling machines in a manufacturing department. (*Courtesy of Cincinnati Milling Machine and Cincinnati Grinders, Inc.*)

The worktable may be moved longitudinally, by hand or automatically, in either direction; this is called the longitudinal feed or more often "table feed." The saddle is so arranged on the knee that it may be moved transversely by hand or power in either direction; this is called the cross-feed. The vertical movement of the knee may be used as a vertical hand feed in either direction, and in the larger sizes automatic vertical feed is provided.

Numerous attachments are built for the universal milling machine which permit of a very large number of distinct operations. It is essentially a toolmaker's milling machine

and is one of the most important, most adaptable and most interesting machines in the shop. Refer to Fig. 158.

The plain milling machine (Fig. 163) is a simplified model of the standard knee-type milling machine. It has largely displaced the bed type for milling a considerable variety of manufactured work. It is very similar in appearance and

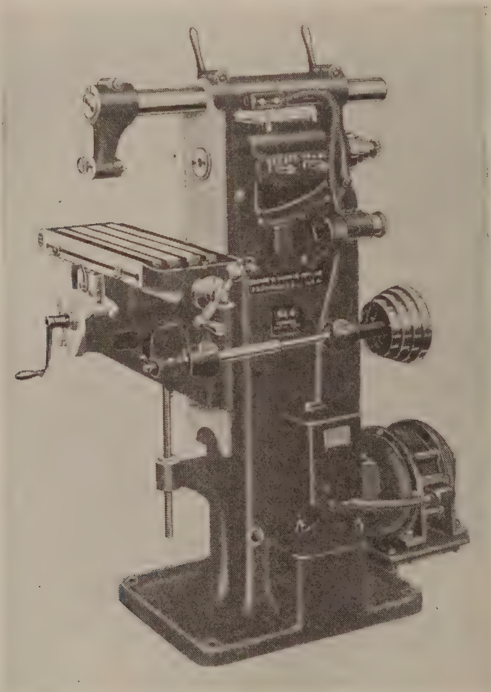


FIG. 163.—No. 0 plain milling machine. A small size and the simplest form of column and knee type. (*Courtesy of Brown & Sharpe Manufacturing Company.*)

construction to the universal milling machine and differs chiefly in that it lacks the swivel-table construction. Many of the attachments made for the universal milling machine can be used on the plain milling machine.

The hand milling machine (Fig. 164) has vertical feed of knee and table, and transverse feed of table by means of screws. The longitudinal feed of the table is through either lever or

screw action. In addition, the spindlehead has a vertical feed, lever-operated.

Ease and speed in setup and operation, for a wide range of work, make this machine especially valuable for the smaller milling jobs, one piece or many.

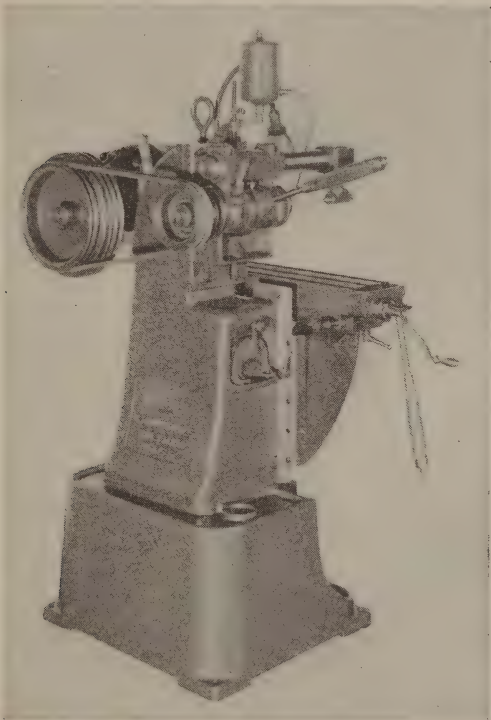


FIG. 164.—Hand milling machine ("Whitney"). (*Courtesy of W. H. Nichols.*)

The vertical-spindle milling machine (Fig. 165) is so called because the axis of rotation of the spindle is vertical. Except for the position of the spindle, it is similar in construction and operation to the plain milling machine. For many end-milling and face-milling operations it is more adaptable than the machine with the horizontal spindle because of the fact that the cutter and the surface being machined are in plain view instead of over back of the work.

173. Parts of the Milling Machine.—On the following pages is illustrated and described an example of the column and knee type of milling machine. Generally speaking, all makes of milling machines of this class have similar features of construction and operation. The spindle-speed changes are

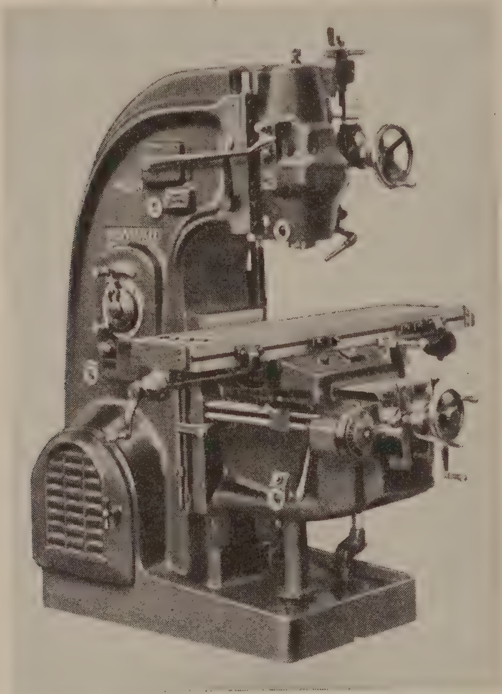


Fig. 165.—Vertical-spindle milling machine. Spindle speeds up to 2,000 r.p.m., table feeds up to 60 in. per min., rapid traverse of 150 in. per min. for table and 75 in. per min. for knee. Sliding head has 4 in. of vertical adjustment with 4-piston stop and micrometer dial for high-production step milling. (*Courtesy of Kearney & Trecker Corporation.*)

controlled by levers or dials, operating through other levers, yokes, and forks, to slide clusters of gears for the various gear runs. The different table feeds—longitudinal, transverse, and vertical—are controlled by levers in a similar manner. All of these machines now have the standardized

spindle nose, use the same kinds of cutters and cutter holding tools, the same vises, and similar types of attachments. The beginner should learn the name and function of each unit and part of the machine on which he is working.

174. The Milling-machine Drive.—While it is true that the use of high-speed-steel cutting tools and the consequent heavy duty required of all classes of machine tools have made imperative many changes in design and construction which must be regarded as now necessary to obtain the best results, and while it is acknowledged that the gear drive or "constant-speed drive" is one of the most important of these improvements, yet it is also true that for many kinds of work the cone-pulley drive is still much used. This is because it is simpler and much less expensive.

The hand milling machines are cone driven and are not provided with back gears. The smaller plain milling machines are cone driven and are usually provided with back gears to give an additional series of speeds. The heavy-duty plain milling machines and usually the universal milling machines are regarded as more efficient when equipped with the constant-speed drive.

175. The Constant-speed Drive.—The general features of the constant-speed drive are as follows: Power is delivered to a wide-faced pulley, which runs loose on a sleeve on the main driving shaft of the machine, through a belt from the countershaft or, in the direct drive, through a silent chain from a motor. By means of a friction clutch on the main driving shaft, operated by a convenient lever, motion is transmitted from the driving pulley to the driving shaft, and from this shaft through selective sliding gears to the spindle. These gears are of heat-treated alloy steel and have integral keys. They are operated by levers or dials at the side of the column. The main driving pulley runs at a constant speed. When the clutch is in, the main driving shaft in the machine runs at the same constant speed. The various spindle speeds are entirely dependent upon the positions of the sliding gears and whether or not the "back gears" are engaged.

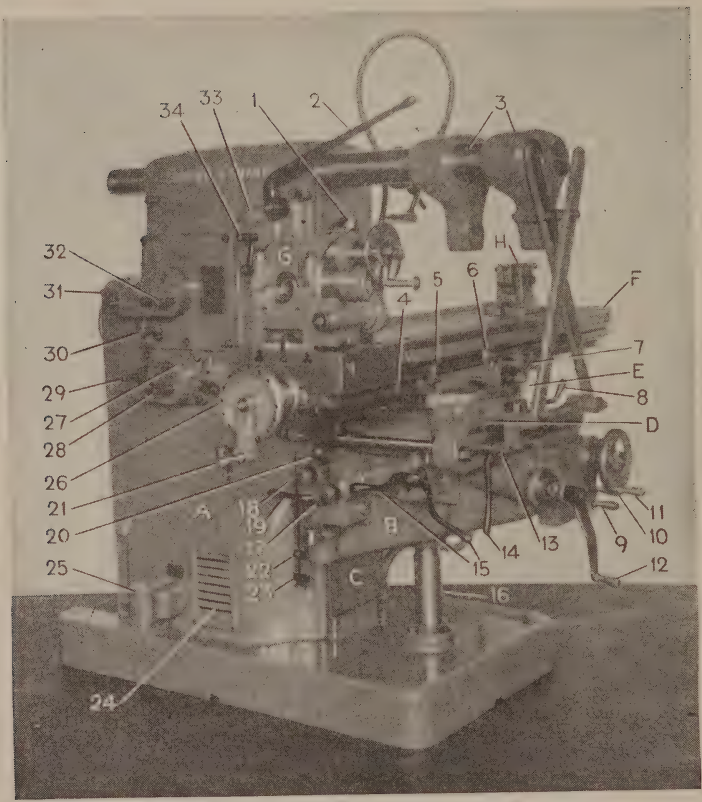


Fig. 166.—Brown & Sharpe universal milling machine.

PARTS OF THE UNIVERSAL MILLING MACHINE

Index to Unit Names

A. Frame, column, and base cast in one piece.

B. Knee, supports the saddle, saddle plate, and table—adjustable vertically.

C. Knee slide, finished front face of column, extends to top of frame to permit of attachments being clamped directly to the face of column.

D. Saddle, has transverse movement on knee.

E. Saddle plate, may be swiveled on saddle, graduated in degrees.

F. Worktable.

G. Headstock of index centers.

H. Footstock of index centers.

Index to Part Names

1. Main spindle, has standardized spindle end with taper hole for centralizing and two large lugs for driving cutter arbors, etc.

2. Friction-clutch lever, for starting and stopping the revolution of the spindle.

3. Overarm and yoke for outer arbor bearing support.

4. Longitudinal table-feed engagement lever. Dual control in front, see 7.

5. Adjustable table dogs have positive stop and trip combined.

6. Adjustable table-feed trip dog, stops feed at any desired point, similar dogs are provided for transverse and vertical feeds, see 22.

7. Longitudinal table-feed engagement lever. Dual control in rear, see 4.

8. Lever for control of fast power feeds in all directions. Dual control in rear, see 26.

9. Engagement lever for power vertical feed [after selective lever (15) is adjusted

The direction of rotation of the spindle is reversed by moving a lever (30, Fig. 166) which serves to slide a driving gear out of engagement with a driven gear and then to bring an intermediate between them, thus changing the direction of the driven gear (see diagram in Fig. 167).

176. Feeding Mechanisms.—In connection with the study of the feeding mechanism the diagram (Fig. 167) should prove interesting and helpful.

Excepting the smaller sizes, milling machines are equipped with a sliding-gear feed-change mechanism which is very similar, in a given machine, to the *speed-change* mechanism employed. The initial feed shaft is driven either from the main spindle as in the smaller cone-driven machine or from the main driving shaft as in the geared-head machine with constant-speed drive. In the first case the amount of feed depends upon the speed of the spindle, and even with a considerable number of feed changes it is often impossible to get a feed fast enough (coarse enough) for the large, slowly revolving cutter, or on the other hand, impossible to obtain a feed slow enough (fine enough) for a small end mill, which to cut

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to the correct position.] Dual control in rear, see 19.

10. Engagement lever for power transverse feed [after selective lever (15) is adjusted to the correct position]. Dual control in rear, see 20.

11. Handwheel for transverse movement of table.

12. Handle for vertical movement of knee and table.

13. Lever for controlling selective series of feed changes. One revolution of the lever for each change of feed. Changes obtained through sliding gears. Direct-reading dial. Dual control in rear, see 28.

14. Knee-clamping lever, for clamping knee to face of column after adjustment.

15. Selective lever for direction of transverse and vertical power feeds. A plate and the pointer on the hub show the three positions: (1) out (transverse), and down (vertical); (2) neutral; (3) in (transverse), and up (vertical). Has handles for operating from both front and rear.

16. Enclosed knee-elevating screw.

17. Hand-crank adjustment for transverse movement of table, see also 11.

18. Hand-crank adjustment for vertical adjustment of table, see also 12.

19. Engagement lever for power vertical feed [after selective lever (15) is adjusted in correct position]. Dual control in front, see 9.

20. Engagement lever for power transverse feed [after selective lever (15) is adjusted to the correct position. Dual control in front, see 10.

21. Longitudinal hand feed of table.

22. Vertical-feed trip dog.

23. Vertical-feed safety dog, throws out the feed at extreme end.

24. Ventilator for motor compartment.

25. Machine drive-chain adjustment.

26. Lever for control of fast power feeds in all directions, see also lever 8.

27. Direct-reading dial indicates longitudinal feed engaged.

28. Feed changes. Dual control in front, see 13.

29. High- and low-feed series selective lever.

30. Spindle rotation reverse lever.

31. High- and low-speed series selective lever.

32. Single lever for controlling selected series of speed changes. One revolution of lever for each change in speed. Changes obtained through sliding gears. Direct-reading dial indicates the speed engaged.

33. Oil gauge, indicates pressure in oiling system.

34. Lever for operating back gears.

efficiently should operate at high speed and comparatively fine feed.

In the second case where the feeding mechanism is operated directly from the *main driving shaft* the feed changes are entirely independent of the spindle speeds, and any combination of speed and feed is available. This is another advantage of the constant-speed drive and is particularly useful in heavy-

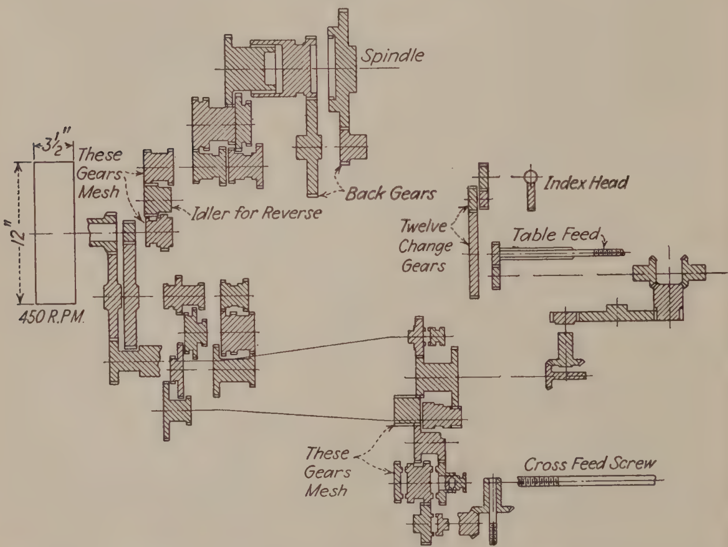


FIG. 167.—Diagram of gears in Brown & Sharpe universal milling machine.

duty milling where slow speed is being used and a coarse feed is wanted.

Conveniently arranged handwheels are provided for hand feed. Power feeds are obtained by means of suitable spur and bevel gears arranged to move the feed screws when connected through positive clutches, and these clutches are engaged or disengaged by levers within easy reach of the operator. In addition, adjustable dogs may be set to trip the feed levers for the purpose of automatically stopping the feed at any desired point. Any feed may be reversed by moving the proper lever.

177. The Table Feed and Bevel-gear Reverse.—The principle of the gearing for the longitudinal table feed is shown in Figs. 168 and 169. These diagrams also illustrate an example of the bevel-gear-reverse mechanism which is used so much in machine construction.

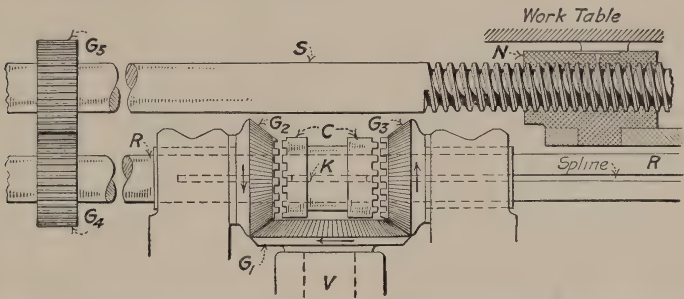


FIG. 168.—Illustrates principle of bevel-gear reversing mechanism as applied to milling-machine table feed. (*Brown & Sharpe.*)

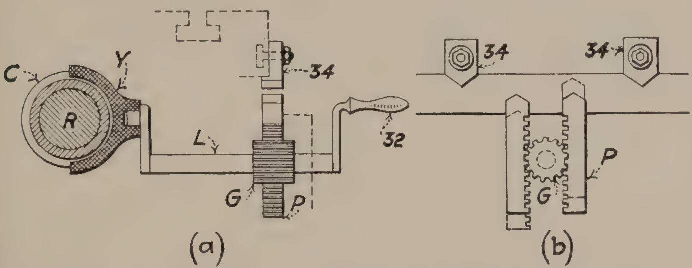


FIG. 169.—Shows principle of operation of sliding clutch member C in Fig. 168. The yoke Y fits freely in the groove in the clutch and is operated by the lever 32 (see also No. 7 Fig. 166). Fastened to the lever shaft L is the gear G that lies between two plungers P which are provided with rack teeth as shown in (b). When lever is in a vertical position the clutch C is neutral. When C is moved to engage either bevel gear (Fig. 168) one plunger is raised and the other is depressed as shown by dotted lines (b, Fig. 169). As the table feeds and the dog 34 comes against and pushes down the plunger P, it turns the gear G which serves to move the lever L and the yoke Y and thus disengage the clutch.

The splined feed rod R and the feed screw S are connected at the left by spur gears. The sliding clutch member C is feathered as at K on the feed rod R and engages clutch teeth milled in the hubs of the bevel gears G_2 and G_3 when moved to the *left* or *right*, respectively, and engages neither when in a

neutral (middle) position. The gears G_2 and G_3 are both free to turn in their respective bearings and are caused to revolve by being engaged with a larger bevel gear G_1 which is mounted on a vertical shaft V below. It is obvious that the gears G_2 and G_3 revolve in opposite directions, and that the direction of rotation of the feed rod R and consequently of the feed screw S (that is, right-hand or left-hand table feed) is dependent upon the position of the clutch member C.

The way in which the clutch member C is moved either by hand or automatically is illustrated in Fig. 169.

ATTACHMENTS

178. Attachments for Milling Machines.[1]—By means of various attachments, which have come to be recognized as practically standard equipment for the column and knee type of milling machine, many jobs can be done more quickly and conveniently than otherwise, and, in addition, a large variety of operations may be performed on one machine that without the attachments would require several kinds of machines.

The manufacturers of milling machines furnish attachments that are interchangeable on their own make of machines of the same size, and many of these attachments, especially those which are clamped to the table, may be used on different sizes of machines or even on different makes of machines.

The index centers (Fig. 170), consisting of the index head and tailstock, comprise the most important attachment for the milling machine. The mechanism of the head is described beginning page 270.

The raising block (Fig. 171) is used when it is required to locate the dividing head at any other than its regular position on the table. It is provided with T slots for the dividing-head bolts. In addition the T slots are accurately milled to fit dividing-head keys and are parallel to a finished edge of the block.

[1] The photographs for the small half-tones in this and the next chapter are furnished through the courtesy of the Brown & Sharpe Manufacturing Company.

The Tilting Table (Fig. 172).—When milling tapers of any description, this attachment is very useful. The vise, the index centers, or the work may be clamped on this table.

The Vertical-spindle Milling Attachment (Fig. 173).—The spindle in this attachment can be set and securely clamped at any angle in a vertical plane, the position being indicated by graduations in degrees. This attachment offers an easy means of doing many kinds of jobs which would be very inconvenient to do with the cutter held in the main spindle, and, more important, makes it possible to produce work that would otherwise require a vertical-spindle milling machine.

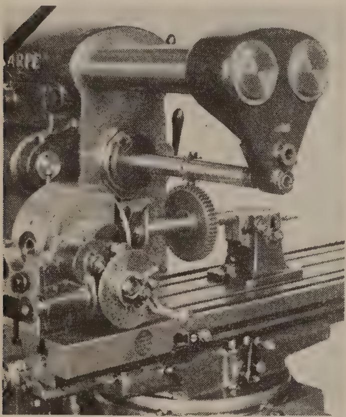


Fig. 170.—Cutting a spur gear. The gear is held on a mandrel between the index centers.

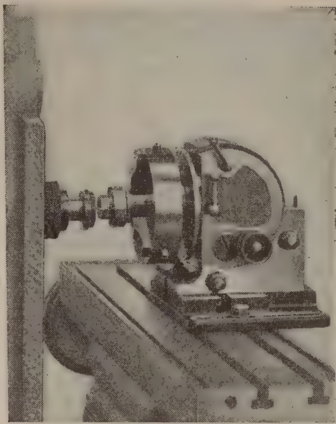


Fig. 171.—Raising block. Shows the head held on the raising block and set around 90 deg.

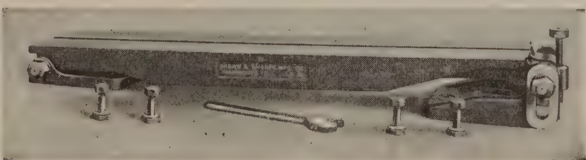


Fig. 172.—Tilting table.

The Universal Milling Attachment (Fig. 174).—The spindle of this attachment may be set and securely clamped at any

angle in either a vertical or horizontal plane, the positions being indicated on the swivel plates by graduations in degrees.

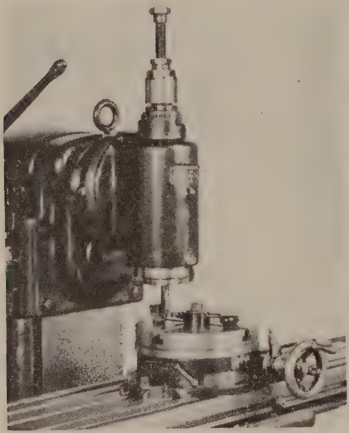


FIG. 173.—Vertical spindle attachment and rotary attachment or circular milling attachment.

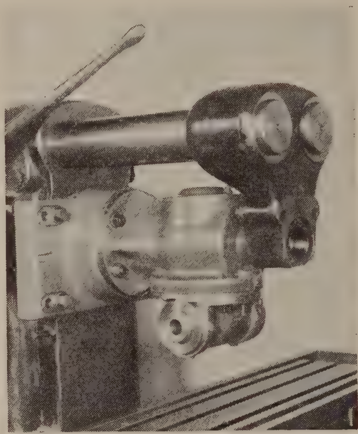


FIG. 174.—Universal milling attachment. Note the two swivels.

Besides having the advantages of the regular vertical-spindle attachment, this attachment offers also the advantages to be obtained by the use of a second swivel at right angles to the first, making it possible to take milling cuts at any angle in either plane.

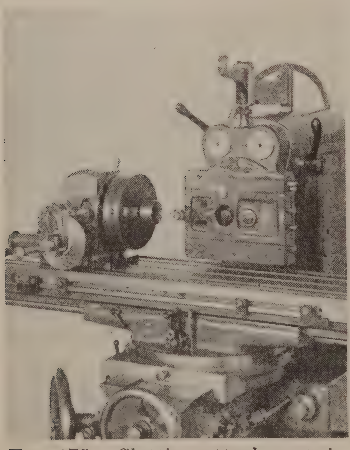


FIG. 175.—Slotting attachment, in horizontal position.

The Slotting Attachment (Fig. 175).—The tool-holding slide has a reciprocating motion and is driven by an adjustable crank which allows the length of the stroke to be changed. The head may be swiveled to 90 deg. either side of center, the position being indicated by graduations in degrees. This attachment is very useful for cutting keyseats

and for finishing the sides of square, oblong, or even irregularly shaped holes such as are frequently needed in medium-sized machine or tool work and especially in making blanking dies. A set of cutting tools which consists of various sizes of rounds, squares, and special shapes is furnished with the attachment. These tools have cylindrical shanks and are secured in the holder by means of a setscrew. It is a simple matter to make special tools of the shape or size required.

The Circular Milling Attachment (Fig. 173).—An especially valuable attachment for a vertical milling machine, or for a

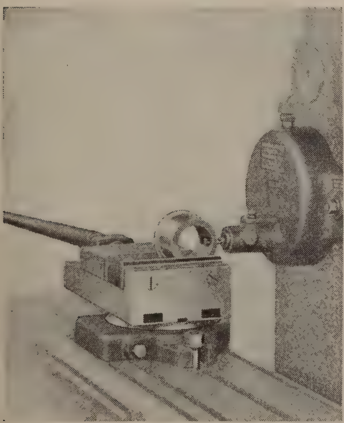


FIG. 176.—High-speed attachment.

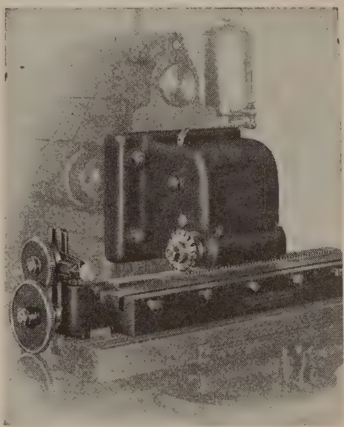


FIG. 177.—Rack-milling attachment.

horizontal machine when used with a vertical-spindle attachment or a slotting attachment. The circular table is rotated by means of an enclosed worm and wormwheel. The smaller size is provided with hand feed only, but the larger size is driven from the feedbox and is provided with an automatic feed trip and adjustable feed-trip dogs. The work as shown in the figure requires a flat cut on top of the lug and a curved surface inside. The curved cut with an exact radius is a simple matter with these two attachments.

The High-speed Milling Attachment (Fig. 176).—Small milling cutters are efficient only when operated at the proper cutting speed. This attachment offers a means of obtaining a

speed from four to six times the regular spindle speeds, since motion is transmitted from a gear fastened to the machine spindle to a pinion about one fourth to one sixth as large on the attachment spindle.

The Rack-milling Attachment (Fig. 177).—This is an almost indispensable attachment if racks more than 10 or 12 in. are to be cut. The cutter is mounted on the end of a hardened-steel spindle which is driven parallel to the table T slots by spur and bevel gears.

At the left of the vise for holding the rack may be seen the rack-indexing attachment. It consists of a bracket fastened to the table and carrying change gears for gearing to the feed screw, and a locking disk. When properly geared one or more whole turns of the disk, to a locking pin, will advance the table an amount equal to the pitch of the rack tooth.

Questions on Milling-machine Construction

1. Clean and oil the finished surface of the column. Loosen the knee clamp and lower the table. What is the advantage of the "telescopic" elevating screw? How is it oiled?

2. How is the knee clamped to the column? What kind of a gib is used? How is the flat-bearing surface oiled?

3. On certain machines a line on the knee-sliding surface of the column marked "center," when split by the top surface of the knee indicates that the index head and tail centers are in same plane with center line of main spindle. Are you able to find this line? With three or four other fellows test your abilities in splitting the line.

4. Clean and oil the table bearing. How much longitudinal feed has the table? How is the table-bearing gib adjusted?

5. Clean and oil the saddle bearings. How much cross-feed has the table?

6. Why should the spindle hole be clean? Why should it be wiped dry?

7. What is the standard taper of the spindle hole? What number of taper is it?

8. How many spindle speeds has this machine? Why so many?

9. What is the normal direction of rotation of the spindle? Why? How is the reverse direction of the spindle obtained?

10. Set the feed mechanism for the slowest feed and throw in the table feed. How far does the table feed in 1 min.?

11. Is the feed in this milling machine independent of the spindle speed?

12. How do you reverse the table feed?

13. Arrange the feed mechanism for the fastest feed. How far does the table move in 1 min.?

14. Is there a power vertical feed? Is there a power cross-feed?

15. How is the cross-feed reversed? Which principle of reversing gears is used in this case?

16. Make a sketch which will show the principle of the bevel-gear-reversing mechanism.

17. Are you able to find in any machine in the shop a bevel-gear reverse in which the clutch operates by friction instead of through clutch teeth (see Fig. 13)? What, in your judgment, are the advantages of each?

18. Are you able to sketch a bevel-gear reverse in which both the reversing gears are keyed to the shaft? (See Fig. 35, Part 1.)

19. What is the reason for having a telescopic feed shaft with universal joints?

20. Which is the most important attachment for the milling machine?

21. How is the raising block used? Are the T slots accurately milled? Give reason.

22. What advantage has the vertical-spindle milling machine? What is the value of the vertical-spindle attachment?

CHAPTER IX

MILLING CUTTERS AND THEIR HOLDING TOOLS

179. Introduction.—Every machine tool has its complement of cutting tools, but, compared to milling cutters the other cutting tools are few in number, simple in form, easy to sharpen, and inexpensive to buy. Do not think, however, that it is difficult to learn about milling cutters; the point is that it is an especially interesting and important subject.

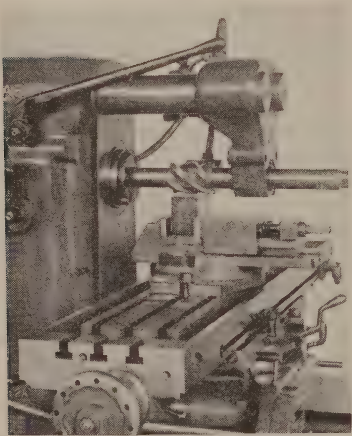


FIG. 178.—Plain milling.

One reason the milling machine is so valuable in toolmaking and in manufacturing, and so interesting to most machinists, is the almost unlimited variety of jobs that are milled, and, of course, the variety of work that may be done is dependent to a certain extent upon the variety of cutters. Also, it is true that the quantity and quality of milled work is particularly dependent upon the shape, size, kind, and condition of the cutting tool and the way it is held.

The purpose of this chapter is to give the student in the beginning of his milling-machine experience an idea of the variety of cutters, how the different cutters are held, and, in as great a degree as may be, an appreciation of what it means to select and set up, to use and care for properly, the milling cutter best suited to the job at hand.

180. Classification of Milling Operations.—There are four distinctly different milling operations, classified as follows:

Plain milling or *slab milling*—the production of a flat surface parallel to the axis of the cutter (Figs. 178 and 179).

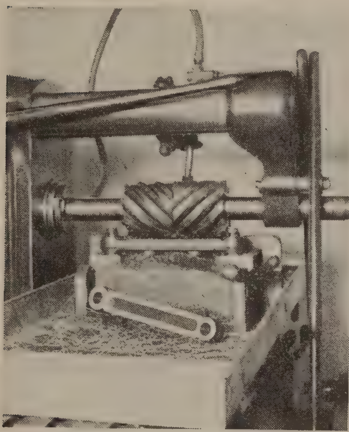


FIG. 179.—Plain milling.

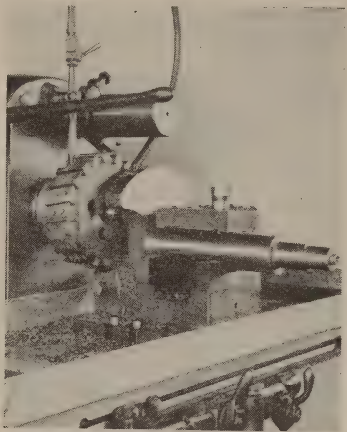


FIG. 180.—Face milling.

Face milling—the production of a flat surface at right angles to the axis of the cutter (Fig. 180).

Angular milling—the production of a flat surface at an inclination to the axis of the cutter (Fig. 181).

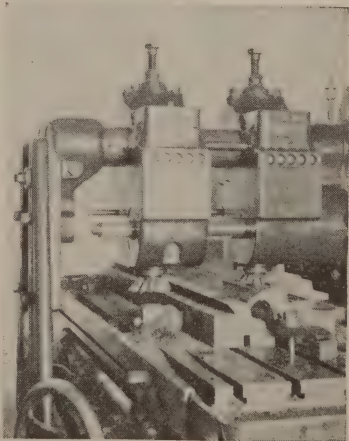


FIG. 181.—Angular milling.

Form milling—the production of a surface having an irregular outline (Fig. 182).

Certain particular operations have their obvious names such as "grooving," "slotting," "sawing" (Fig. 183), and "gear cutting." (See Fig. 170.) "Milling flutes" is a term applied to the grooving of drills, reamers, and taps (Fig. 184). When two or more cutters are used together on one arbor, the operation is called "gang milling" (Fig. 185,

also Fig. 182). Face milling is sometimes called "side milling," and "straddle milling" is the term applied when two side-milling cutters are used and two sides of a piece are milled at the same time (Fig. 186). An example of the use of an end mill is shown in Fig. 173. "Profiling" is milling to a predetermined outline by means of a guide bar and template. (A profiling machine is illustrated in Fig. 161.) "Routing" is milling to a more or less irregular outline while guiding by hand.

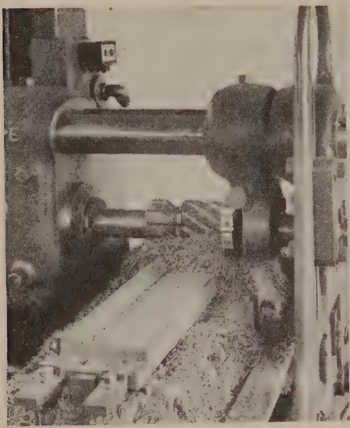
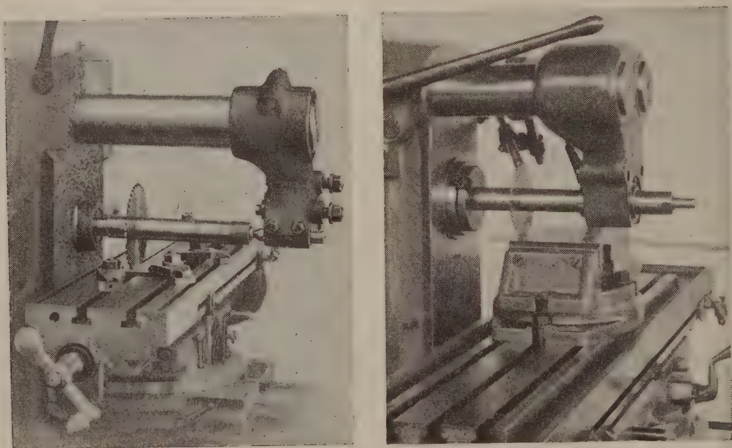


Fig. 182.—Form milling.

181. Milling Cutters—Introduction.—From the illustrations of the kinds of milling operations given, it will be apparent that a great variety of kinds and sizes



(a) (b)

Fig. 183.—(a) Sawing; (b) cutting off stock.

of milling cutters are used. There are, in fact, over 100 different kinds of cutters on the market, made in over 4,000

different stock sizes, one company alone making over 3,600 different stock sizes of cutters.

It is not enough to know that there are many kinds and sizes of cutters. The machinist should know the *names* of the cutters, and in a general way the *sizes* that may be obtained. He should know the *uses* of the cutters. The same cutter may be used for a variety of operations, and on the other hand any one of a number of kinds of cutters may be

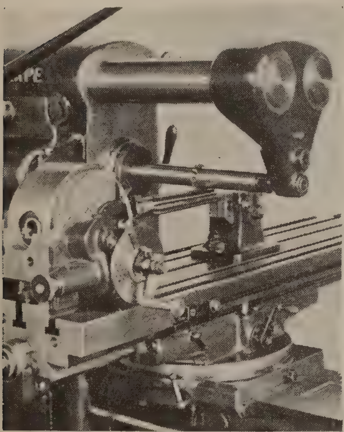


Fig. 184.—Milling grooves.

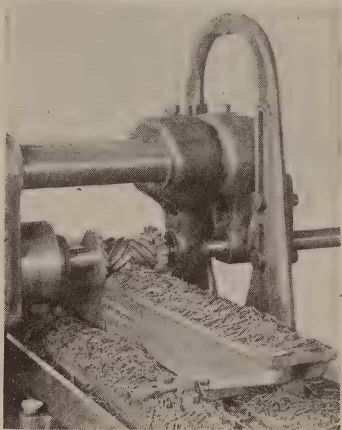


Fig. 185.—Gang milling.

used to perform a given operation. In milling, as in other machine-shop work, the resourcefulness of the machinist is often taxed to perform the given operation. For example, the best cutter to use may not be available, but another kind of cutter may do almost as well, and the job finished without delay.

It is easy enough to become familiar with the names and sizes, but to get acquainted with *uses* of the various cutters will require more time and greater effort.

Learn to call for cutters by their name and the size required. Do not be satisfied to use a cutter, the family name, given name, and general characteristics of which you do not know. Get an idea of what the rest of the family, the big ones and the

little ones, are like. For example, in a watch factory is used a slitting cutter 1 in. diameter, $\frac{1}{64}$ in. thick; in an armor-plate mill is used a similar cutter, same family, 6 ft. diameter and 2 in. thick. How many sizes of metal-slitting cutters are you able to find in the toolroom? How many sizes are given in a catalogue of cutters?

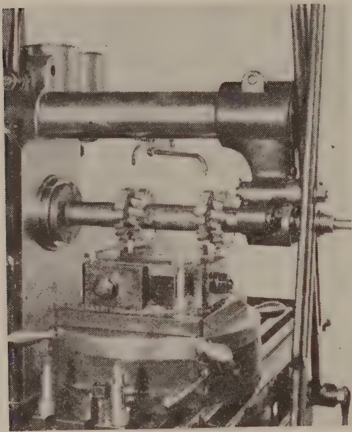


FIG. 186.—Straddle milling.

Learn the uses of the cutters by study, reasoning, asking questions, and observation. One young man who intelligently uses his "head," his tongue, his ears, and his eyes is worth any number of mentally lazy fellows. Look around and size it up for yourself.

TYPES OF MILLING-CUTTER TEETH

There are three distinct kinds of teeth used in the manufacture of milling cutters. *The saw tooth*, the *formed tooth*, and the *inserted tooth*.

182. The Saw Tooth.—Until the last few years the saw tooth (Fig. 187) was almost universally used for all kinds and shapes of milling cutters. It is the cheapest type of tooth to produce either in a straight or spiral form and is still largely used in end mills, metal-slitting cutters, and the smaller sizes of plain milling cutters. It will be observed that the cutting edge is given clearance by backing off the "land" about 5 deg. This is done in the cutter grinder when the cutter is sharpened (see page 228).

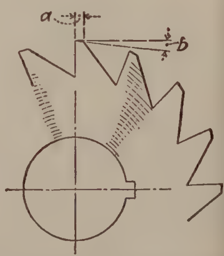


FIG. 187.—Shows the clearance (b) on the land (a) of a saw tooth of milling cutter.

The cut (Fig. 187) shows a *radial* face of tooth. The tendency is to give the coarser tooth cutters about 10 deg. rake.

183. The Formed Tooth.—One of the chief values of the milling machine is the production of a large number of duplicate pieces having curved, shouldered, or other irregular surfaces. This kind of work can be done very much quicker in the milling machine than in any other machine, such as the shaper or planer. Also a very large number of pieces may be

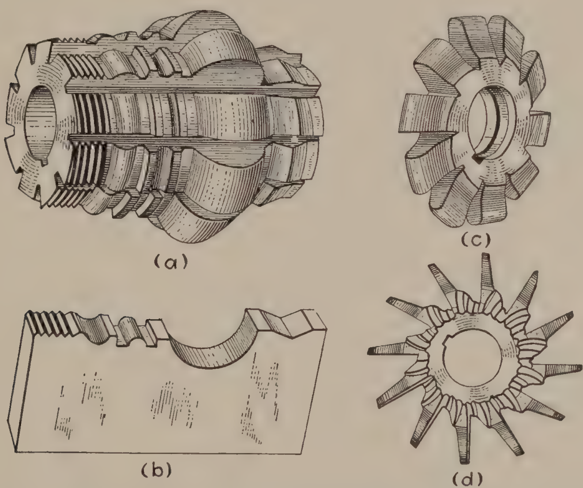


Fig. 188.—Formed cutters. In (*a*) is shown a very special formed cutter, and in (*b*) the milled piece; (*c*) illustrates a gear cutter. Practically all gear cutters used in milling machines are "formed" cutters. All formed cutters are sharpened by grinding the face of the tooth *radially*, and (*d*) shows a gear cutter which has been sharpened many times, but whose contour has not been changed.

milled without changing the setting of the machine, thus making it possible to use more or less inexperienced workmen and still produce a fine and accurate grade of work. Owing to the fact that the so-called saw tooth of an irregular outline cannot be sharpened without changing the contour of the cutting edge, this tooth has been largely superseded, in the milling of irregular surfaces, by what is known as the formed tooth. For finishing certain irregular shapes to an exact out-

line, the use of the formed-tooth cutter (Fig. 188) in the milling machine is the most efficient method. A surface with an undercut cannot be finished in this way, but for most other irregular surfaces of a size not too large, and a quantity production that will warrant the cost of the cutter, this kind of cutter is advantageous. The formed cutter may be used if desired with other cutters to make up a gang (Fig. 182). The special advantage of the formed cutter lies in the fact

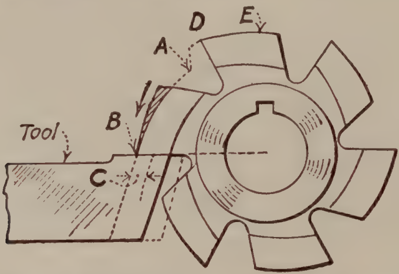


FIG. 189.—Backing off a formed cutter. Note the eccentric curve of the land of the tooth; the tooth has been "backed off" or "relieved" or "given clearance" an amount equal to the shaded portion above B. As the cutter revolves and the point A approaches the point B, the tool moves "in" and when point A has reached point B the tool has moved in an amount equal to C. Then the tool snaps back ready to start at D its motion "in" to back off the next tooth E. A slow speed and a very fine feed (cross-feed) is necessary.

that it may be sharpened many times without changing the shape of the cutting edge if, when sharpened, the *face of the tooth is ground radially.*

The formed cutter is made by leaving a land of considerable width between the grooves and then backing off or relieving this land eccentrically. This is accomplished in a special machine or in a lathe having a relieving attachment, by means of a forming tool of the correct shape, so held that its face is on a radial line with the cutter, that is, "on center," and so arranged in the machine or attachment as to automatically *feed in* to back off the land of each tooth and snap back through the tooth space ready for the next tooth, as the cutter slowly revolves (Fig. 189).

184. The inserted-tooth cutter (Fig. 190) has become very popular since the advent of high-speed steel. Cutter blades

made of high-speed steel are inserted and rigidly held in a blank made of machine steel or cast iron. There are various methods of holding the blades employed by the different manufacturers. Inserted-tooth cutters are especially efficient for the reasons that they are economical in the first cost and the worn-out or broken blades can be replaced by new blades. It is an especially desirable way of making large cutters.

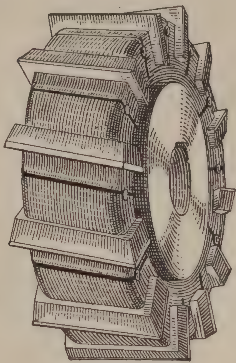


FIG. 190.—Inserted-tooth cutter.

185. Kinds of Milling Cutters. *Plain Milling Cutter.*—The most common form of milling cutter is known as the plain milling cutter (Fig. 191), which is merely a cylinder having teeth cut upon its periphery for the purpose of producing a surface parallel to the axis of the cutter. When over ¾ in. wide the teeth are usually cut on a spiral. The object of the spiral tooth is to give a shearing cut. The shearing cut reduces the stress upon the tooth by preventing a distinct shock which occurs in a cutter with straight teeth when each tooth starts to take its chip. The spiral-tooth cutter produces a

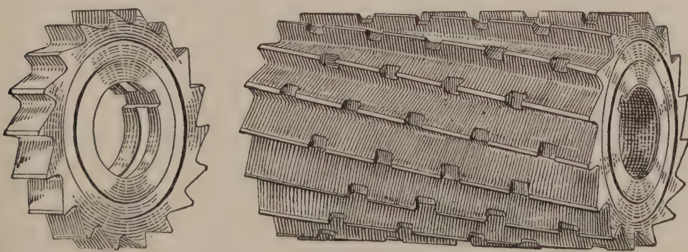
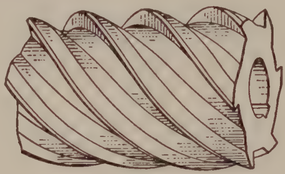


FIG. 191.—Plain milling cutters.

better and smoother finish, requires less power to operate, and reduces the tendency to chatter. It has *smooth action.* When of considerable length relative to the diameter, these cutters are called "slabbing cutters." Slabbing cutters are frequently made with nicked teeth, the nicks following each

other alternately. The object of the nicks is to break up the chip and make it possible to take a coarser feed.

Right- and left-hand spiral cutters may be mounted together on the arbor when taking heavy cuts, to avoid excessive end thrust on the machine spindle (see Figs. 179 and 185).



(a)

(b)

FIG. 192.—Helical milling cutters: (*a*) hole type; (*b*) arbor type.

When a cutter has an especially steep spiral (Fig. 192), it is called a *helical milling cutter.* Increasing the spiral (helix angle) to the degree shown seems to give increasingly smoother action. Figure 192 illustrates both the hole type and the arbor type.

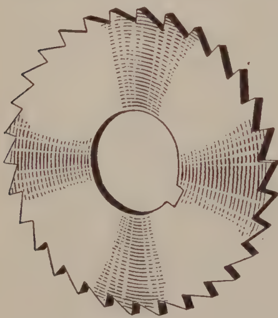


FIG. 193.—Metal-slitting cutter.

Metal-slitting Cutter (Fig. 193).—This is essentially a thin plain milling cutter, the sides of which are finished true by grinding. These cutters are ground a little thinner towards the center, that is, they are given clearance toward the center in order that the sides of the cutter will not rub in the groove.

Side-milling Cutter.—Figure 194 shows a side-milling cutter. This is a plain milling cutter with the addition of teeth on both sides. "Side mills" are frequently used in pairs with a collar between, and when so used are often called "*straddle mills.*" Pieces such as bolts, nuts, tongues, etc., that are to be milled on two parallel sides can be easily and accurately machined with a pair of side mills.

For milling slots to a standard width the interlocking side milling cutter (Fig. 195) may be used. This cutter is made in two parts, in fact there are two distinct cutters, with the inner surfaces of both parts milled to interlock. Even with repeated sharpenings the correct width of the slot may be maintained by placing thin metal washers between the hubs. If the cutters were not "interlocking" a ridge as wide as the space between the cutters would be left in the work.

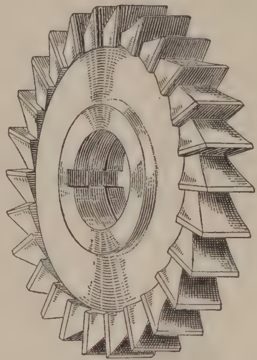


Fig. 194.—Side-milling cutter.

End Mills.—These cutters have teeth on the periphery and at the end (see Fig. 196). Most end mills have a taper shank which fits into a collet (Fig. 212) or an adapter (Fig. 213). End mills may be used for a large variety of light milling operations such as machining the edges of fairly thin pieces, for squaring the ends of smaller pieces and often for making a corner cut (shoulder) where a fillet is desired. For slots or keyways it is often impossible to use any other form of cutter. End mills of a size over ¼ in. are usually made with spiral teeth.

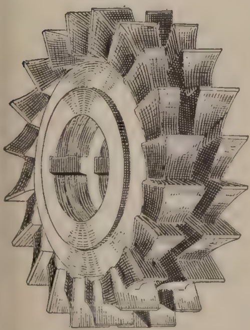


Fig. 195.—Interlocking side-milling cutter. Note the thin and thick "interlocking" sections.

Cotter Mill.—In *d*, Fig. 196, is represented a two-lipped slotting end mill sometimes called a cotter mill (from the English term "cotter" or key). It is used for cutting slots and keyways. These mills, having end teeth to the center similar to the lips of a drill, may be used for milling deep slots from the solid metal where there has been no drilled hole provided for starting the cut. The best results are obtained by a high surface speed with (1) a fairly deep cut and fine feed, or (2) a fairly shallow depth of cut with a medium feed. Use plenty of cutting lubricant.

Shell End Mills.—End mills over 2 in. in diameter are made detachable from the shank as shown in Fig. 197. These are known as *shell end mills* and are designed for the purpose of

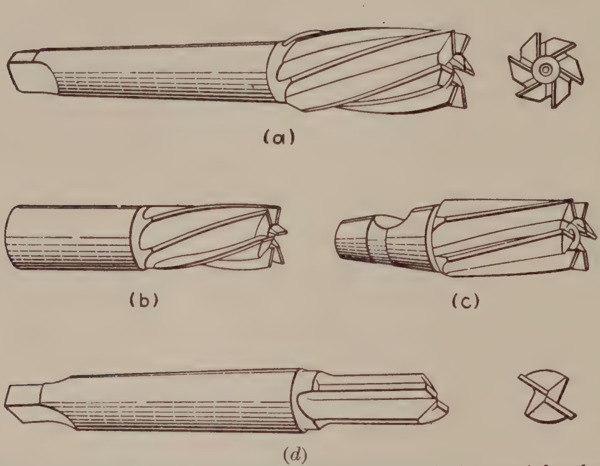


Fig. 196.—End mills: (*a*) taper-shank spiral end mill; (*b*) straight shank; (*c*) cam-lock shank; (*d*) two-lip end mill.

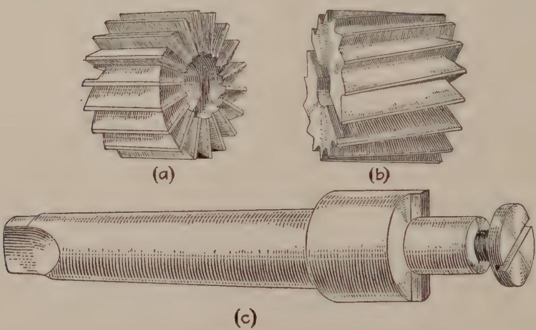


Fig. 197.—Shell end mills and arbor.

economy in replacing the cutter without necessarily replacing the shank. Shell end mills have a standard-sized hole of the proper diameter and have a slot milled diametrically across

the back to fit a tongue on the arbor. The cutter is held on the arbor by a cap screw. (See also Fig. 214.)

Facing Cutter.—The larger sizes (diameters) of cutters having teeth on one end or face are not provided with shanks but are fastened on the end of the machine spindle. They are

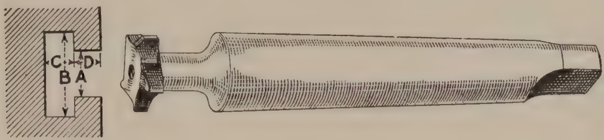


FIG. 198.—T-slot cutter

STANDARD T SLOTS

Diam. of bolt	Width of throat A	Width of T slot B		Depth of T slot C		Depth of throat D	
		Max.	Min.	Max.	Min.	Max.	Min.
$\frac{1}{4}$	$\frac{9}{32}$	$\frac{9}{16}$	$\frac{1}{2}$	$\frac{15}{64}$	$\frac{13}{64}$	$\frac{3}{8}$	$\frac{1}{8}$
$\frac{5}{16}$	$\frac{11}{32}$	$\frac{21}{32}$	$\frac{19}{32}$	$\frac{17}{64}$	$\frac{15}{64}$	$\frac{7}{16}$	$\frac{5}{32}$
$\frac{3}{8}$	$\frac{7}{16}$	$\frac{25}{32}$	$\frac{23}{32}$	$\frac{21}{64}$	$\frac{19}{64}$	$\frac{9}{16}$	$\frac{7}{32}$
$\frac{1}{2}$	$\frac{11}{16}$	$\frac{31}{32}$	$\frac{29}{32}$	$\frac{25}{64}$	$\frac{23}{64}$	$\frac{11}{16}$	$\frac{5}{16}$
$\frac{5}{8}$	$\frac{7}{8}$	$1\frac{1}{4}$	$1\frac{3}{16}$	$\frac{31}{64}$	$\frac{29}{64}$	$\frac{7}{8}$	$\frac{7}{16}$
$\frac{3}{4}$	$1\frac{1}{16}$	$1\frac{15}{32}$	$1\frac{3}{8}$	$\frac{5}{8}$	$\frac{19}{32}$	$1\frac{1}{16}$	$\frac{9}{16}$
1	$1\frac{1}{4}$	$1\frac{17}{32}$	$1\frac{3}{4}$	$\frac{53}{64}$	$\frac{25}{32}$	$1\frac{1}{4}$	$\frac{3}{4}$
$1\frac{1}{4}$	$1\frac{9}{16}$	$2\frac{7}{32}$	$2\frac{1}{8}$	$1\frac{3}{32}$	$1\frac{1}{32}$	$1\frac{9}{16}$	1
$1\frac{1}{2}$	$1\frac{15}{16}$	$2\frac{21}{32}$	$2\frac{9}{16}$	$1\frac{11}{32}$	$1\frac{9}{32}$	$1\frac{15}{16}$	$1\frac{1}{4}$

The minimum diameter of the width of throat A is the diameter of the bolt. The cutter is made maximum sizes (B and C) to allow for sharpening. The diameter of the neck of the cutter is made a trifle smaller than the bolt size for clearance, and the length of the neck is somewhat longer than the maximum depth of throat D.

called face-milling cutters or face mills and are usually made with inserted teeth (see Fig. 180).

T-slot Cutter (Fig. 198).—This form of cutter is used for finishing T slots in worktables, etc. The central groove is milled with a side mill or an end mill, and then the wider part is milled with the T-slot cutter. It will be observed that every other tooth is cut away alternately on each side. This makes for greater freedom of chip movement and greater ease in sharpening.

Angular Cutters (Fig. 199).—The cutting teeth of an angular cutter are neither parallel nor perpendicular to the axis of the cutter but are at some oblique angle such as 60, 70, or 80 deg. These cutters are used to cut teeth in ratchet wheels, for milling dovetails, etc. Sometimes the straight side is provided with teeth to give a better finish with this side when cutting grooves.

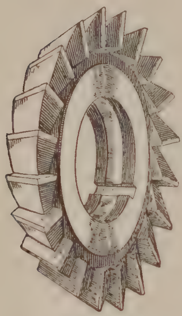


FIG. 199.—Left-hand angular milling cutter.

Double-angle Cutters.—In Fig. 200 at *a* is shown a double-angle cutter which is used for cutting spiral teeth in milling cutters, etc., and *b* illustrates how this cutter is set to obtain a radial tooth. These cutters are usually made with an angle of 12 deg. on one side and 40, 48, or 53 deg. on the other. The illustration shows a formed-tooth cutter which has a much longer life than the saw-tooth cutter. Double-angle cutters as shown, either right-hand or left-hand, also double-angle cutters for milling symmetrical 90-deg. *V*'s are made in many sizes with either saw teeth or formed teeth.

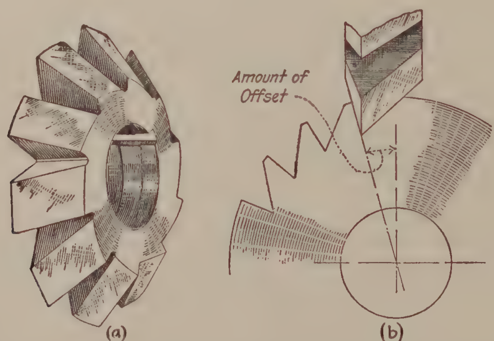


FIG. 200.—(*a*) Double-angle cutter, left-hand, for fluting cutters with saw-like teeth either straight or spiral; (*b*) shows cutter off set to give radial face.

Tap and Reamer Cutter.—Figure 201 illustrates a cutter for grooving taps and reamers and *a* and *b* show the manner in which the cutter is set to give a radial tooth. This cutter is substantially a double-angle formed-tooth cutter with the

points of the teeth well rounded. Tap and reamer cutters are made in several sizes, and each size is stamped with the range of the diameters of taps and reamers for which it may be used.

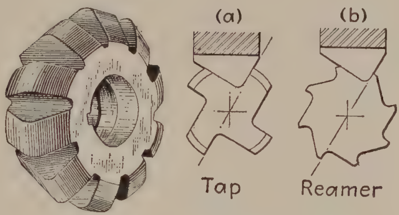


FIG. 201.—Tap and reamer cutter.

FIG. 202.—Corner-rounding cutters.

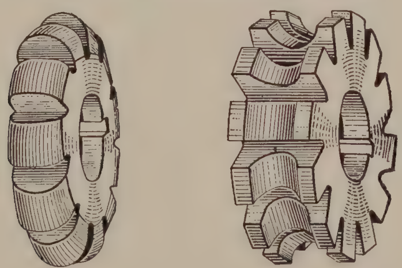


FIG. 203.—Convex and concave cutters.

Corner-rounding Cutters.—Figure 202 shows left-hand, double, and right-hand corner-rounding cutters which are used for the purpose of finishing the corners and edges of work. These cutters are made for any desired radius.

Convex and Concave Milling Cutters.—Figure 203 shows convex and concave formed milling cutters used for milling half circles or parts of half circles.

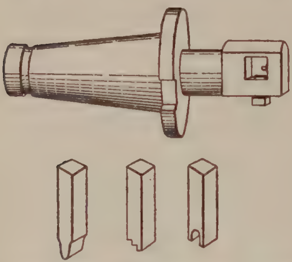


FIG. 204.—Fly-cutter arbor and typical cutters.

Fly Cutter.—The simplest form of cutter is the fly cutter, several shapes of which are shown in Fig. 204 together with the *fly-cutter holder* or *arbor.* It is a very useful form of cutter for experimental or hurry-up jobs where it would be impracticable on account of the time and expense necessary to make a regular formed cutter. It is simply a piece of square steel, the end of which is formed (usually filed) to the desired shape, backed off and hardened. The shank of the arbor fits the taper hole in the milling-machine spindle, and the tool should be tightly clamped in the arbor. A fly cutter in use is shown in Fig. 205.

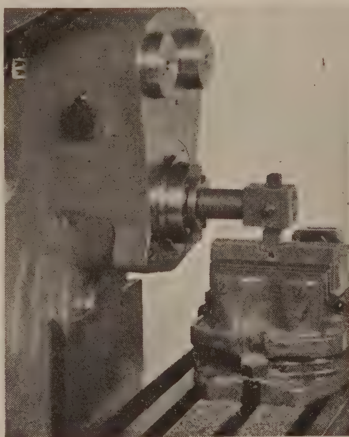


FIG. 205.—Using a fly cutter. Set the spindle speed for the diameter of the *swing* of the cutter. Use fine feed.

186. Right-hand and Left-hand Cutters (Fig. 206).—Milling cutters are said to cut right-hand or left-hand according to the direction in which the cutter revolves when observed from the *back* of the machine or the back of the cutter. Cutters may be mounted on an arbor to be used either way, but angular cutters are marked *R* or *L* assuming the angular teeth to be on the back side. Attention is called to the fact that a *left-hand* end mill is given a *right-hand* spiral, and vice versa, in order that the reaction against the tooth as it peels off the chip will tend to force the cutter toward the spindle rather than to loosen it. This is true also of spiral slabbing mills.

It is customary, however, in heavy gang milling, as shown for example in Fig. 179, to use both right-hand and left-hand *spirals* to balance the force against the spindle-thrust bearing.

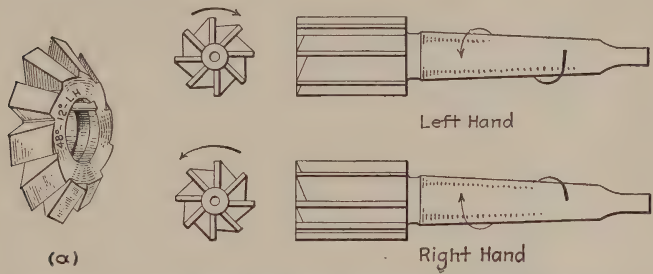


FIG. 206.—Right-hand and left-hand cutters; (*a*) shows 48-and 12-deg. left-hand double-angle cutter.

187. Advantages of Coarse Teeth (Fig. 207).—The many practical experiments and tests that have been made with the purpose of developing efficient milling cutters have clearly demonstrated the following advantages of the coarse tooth

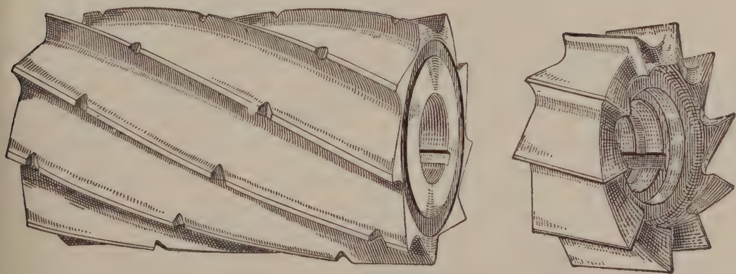


FIG. 207.—Coarse-tooth milling cutters.

cutters with the increased spiral, as compared with the previously recognized standards:

1. Ample chip space.

2. Increased strength of tooth.

3. Teeth may be undercut a little, that is, given *rake*, more advantageously.

4. More nearly perfect shearing cut, that is, less power required to remove a given amount of metal.

5. Free cutting action (larger chip per tooth) eliminating tendency of cutting edge to scrape or slide instead of cut, causing less friction and consequently less heat.

6. Longer life, less need for grinding; also may be ground greater number of times and with less time spent at each grinding.

7. Notches, with clearance both sides, break the chip.

These advantages may be summarized thus: These cutters are capable of much greater production than the older style of cutter, and use comparatively less power.

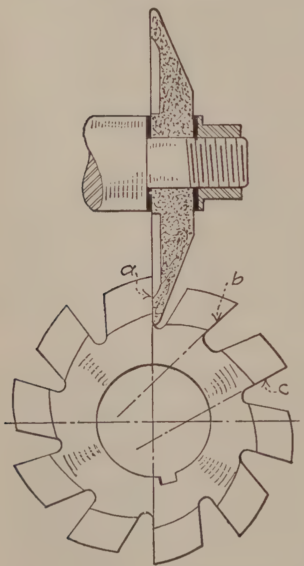


Fig. 208.—Sharpening a formed cutter. Tooth sharpened on face radially as at *a* will cut its shape; if ground hooking as at *b*, or dragging as at *c*, it will not cut correct shape.

188. Sharpening Cutters.—A milling cutter, like any other cutting tool, will do good work when it is correctly sharpened and under proper conditions will do a considerable amount of work before it is noticeably dull. If, however, it is operated when noticeably dull, the excessive friction generates heat enough to soften the teeth, and it will soon become *very dull* and possibly ruined.

To sharpen a dull cutter takes only a few minutes and reduces each tooth only a small amount. To sharpen a *very dull* cutter takes a long time and a large portion of each tooth must be sacrificed. "Keep cutters sharp."

Formed cutters are sharpened by grinding the face of the tooth radially, and every tooth alike. If one tooth is ground less than another it is longer and consequently cuts more than its share and dulls quickly. When not ground radially, they are either "booking" as at *b*, Fig. 208, or "dragging" as at *c*.

In either case the true profile is not produced because the teeth are so made that the outline of the cutting edge is correct only when the teeth are ground radially.

Cutters with saw teeth or inserted teeth are sharpened by grinding the lands. The angle of tooth clearance is a very important consideration. The clearance is the amount the top of the tooth (the land) is relieved (or "backed off") so that this part of the tooth will not rub on the work after the cutting edge has passed. If the clearance is too great the cutter dulls rapidly and if not enough the cutter rubs and does not cut. The proper clearance angle should be about 7 deg. for cutters under 3 in. in diameter, and about 5 deg.

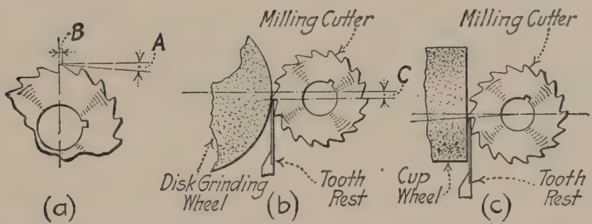


FIG. 209.—Grinding the clearance on milling cutters. The angle of tooth clearance is measured from a line at right angles to the radial as shown, *A* representing the clearance, and *B* the land of the tooth. To obtain the clearance, the tooth rest must be a given distance below the center of the cutter as shown in (*a*) and (*c*). For the amount *C* to set the tooth rest below center, see Table 14, page 491.

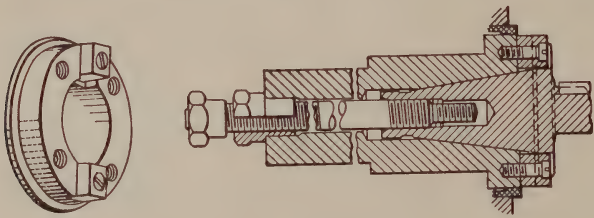
for those over 3 in. The clearance on end teeth (and side teeth) should be about 2 deg., and in order to avoid the tendency to drag and thus score the surface of the work they should be ground 0.001 or 0.002 in. lower toward the center. That is, placing a scale across the diameter of the cutter would show the end (or face) to be slightly concave.

The various manufacturers of cutter grinders furnish booklets illustrating and explaining the operation of their machines, and the operator, the beginner especially, will find such information very helpful. The information given in connection with Fig. 209 is fundamental and applicable in any cutter-grinding machine.

When grinding cutters use a soft wheel of medium grain (see Grinding Wheels). Keep the wheel clean and true and take light fast cuts to avoid drawing the temper of the cutter.

HOLDING THE CUTTER

189. The Standardized Spindle End (Fig. 210).—The revolving main spindle of the milling machine carries with it the cutter. The spindle is designed to hold and drive the cutter whether arranged on an arbor, in an adapter, in a collet, or screwed on the nose of the spindle. Formerly the taper shank



(a) (b)

Fig. 210.—Standardized spindle end. The method of holding arbors and adapters is shown in (*b*). The larger thread on the end of the draw-in bolt is used in most cases, but certain adapters, collets, etc. require the smaller thread.

of the arbor was 0.5 in. per ft. B. & S. taper (Fig. 211), and the end of the shank was provided with a tang to help hold and drive; but the present design which fits the new standard spindle end gives a much simpler and stronger drive besides many other advantages.

Manufacturers have adopted a standard spindle end and a complete series of arbors for all sizes of milling machines from 2- to 20-hp. In addition to securing interchangeability of all arbors and face-milling cutters in all makes of milling machines, and the consequent elimination of the great variety of sizes and kinds, the standard has retained and improved the best features of the older design.

1. The arbors are driven by two lugs instead of depending upon the hold of the taper plus the tang.

2. Since the taper is not used for frictional holding, but merely for centralizing the arbor or adapter, it is made with a steeper taper, 3½ in. instead of ½ in. per ft. Therefore the new design of arbor cannot "stick" in the spindle, and is quick releasing.

3. A draw-in bolt is used to pull the arbor tightly in place, obviating any chance of spoiling the work by the loosening of the arbor.

4. To remove the arbor, merely loosen the draw-in bolt part of a turn, tap the bolthead lightly, and then completely unscrew the bolt.

5. The entering end of the arbor is straight, and enters a straight part of the spindle hole, in order to have the tapped hole in line when putting in the drawbolt.

6. Various kinds of adapters are manufactured to make possible the use of older types of arbors, etc., in the newer machines.

7. An extension threaded end is provided on the drawbolt for securing auxiliary equipment, such as certain kinds of adapters.

8. Face-milling cutters are centralized on the spindle end, held by four bolts and driven by the two lugs.

190. Milling-machine arbors are made in various lengths and in standard diameters of ⅞, 1, 1¼, and 1½ in. Figure 211 shows new and old style. The difference between the old and new is in the taper shank. The shank of either is made to fit the taper hole in the spindle, and the other end is threaded to receive a nut. The remaining portion of the arbor is made cylindrical. Collars are fitted freely over this part of the arbor and by means of the nut one or more cutters may be clamped between the collars. The collars, being of different lengths and removable, permit of cutters of various lengths (or thicknesses) being clamped and also permit of locating the cutters in the desired position on the arbor. The arbor is supported by the yoke from the overarm either by a center or in a bearing in the yoke. The bushing *B* which forms the journal in the outer bearing for supporting the

arbor is of somewhat larger diameter than the collars and is ground to fit a bronze bearing in the arbor yoke. To avoid spring of the arbor, the bearing should always be located as close to the cutter as will allow the yoke to clear the work and the vise or fixture that holds the work. For the same reason, the center should not be used unless it is impracticable to use the bushing in the bronze bearing.

The friction between the collars and cutters is sufficient to hold the cutter for light cuts, but for heavy duty, the cutter should be keyed. Arbors are usually splined for keys.

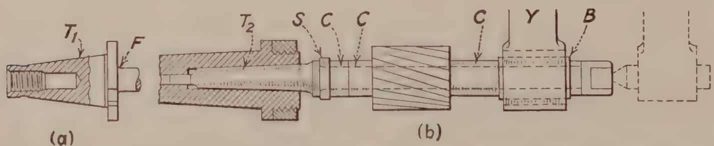


FIG. 211.—Milling-machine arbor: T_1 shows modern type of taper shank; T_2, old type of taper shank. *F*, fillet, gives extra strength and stability; *S*, special collar to cover fillet; *C*, regular collars; *B*, special collar fits bronze bearing in yoke *Y*. The outer end of the arbor is threaded for the nut. In those machines (Brown & Sharpe for example) where the cutter normally runs left-hand the arbor and nut are threaded left-hand, and thus the pressure of the cut does not tend to loosen the nut. Dotted lines show yoke center in end of arbor.

Arbors which have the ½-in. per ft. taper shank (old style) are driven home with a babbitt ball and are removed by means of a knockout rod.

191. The Collet for Taper-shank Mills.—End mills up to 2 in. in diameter are usually made solid with the shank. The shank, of a size to conform to the size of the cutter, may be (rarely) straight, or Brown and Sharpe taper (½ in. per ft.), or, more recently, the steeper, 3½-in. per ft. taper. Unless the size of the B. & S. taper shank is the same as the taper hole in the spindle, it is necessary to use a collet (Fig. 212) to hold the cutter. It must be very carefully driven home with a babbitt ball, or a brass or copper rod. A milling-machine collet is the same sort of tool as the drill-press *socket* or the lathe *sleeve*, in that it serves to step the sizes of tapers. The taper, however, is *not* the same.

192. The Brown and Sharpe Cam Lock.—End mills with the steeper taper are held with the cam-lock adapter (Fig. 213). This adapter for stepping the steep-taper sizes gives a method of securely holding end mills and the like, that requires no

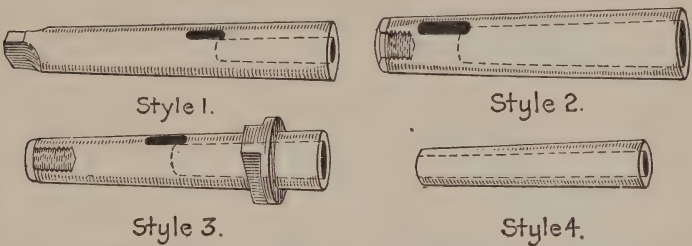


FIG. 212.—Milling-machine collets. For adapters for standardized spindle end see Fig. 214.

pounding with babbitt hammer or otherwise. A simple turn of the wrench turns a cam which quickly locks or releases the cutter.

All necessary cam-lock adapters, as well as the corresponding taper-shank end mills, and kindred cutters of every descrip-

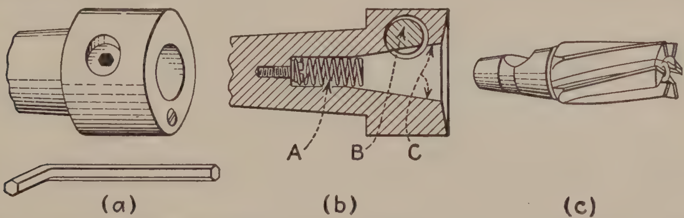


FIG. 213.—(*a*) Brown & Sharpe "cam-lock" adapter. (*b*) Sectional view showing: *A*, the spring to keep the shank of end mill floating to insure correct seating; *B*, cam-lock, draws end mill securely into taper and locks it there; *C*, standard milling-machine taper for quick release. (*c*) End mill with cam-lock shank.

tion, are commercially manufactured. Examples are illustrated in Fig. 214.

193. Holding Straight-shank Cutters.—End mills with straight shanks (*b*, Fig. 196) may be used if a special holding chuck is provided. Their cost is somewhat less than that of taper-shank mills of the same size, and in the smaller sizes they are very satisfactory. Most Whitney keyway cutters are

made with straight shanks. Figure 215 shows a keyway cutter held in the spring chuck or "spring collet."

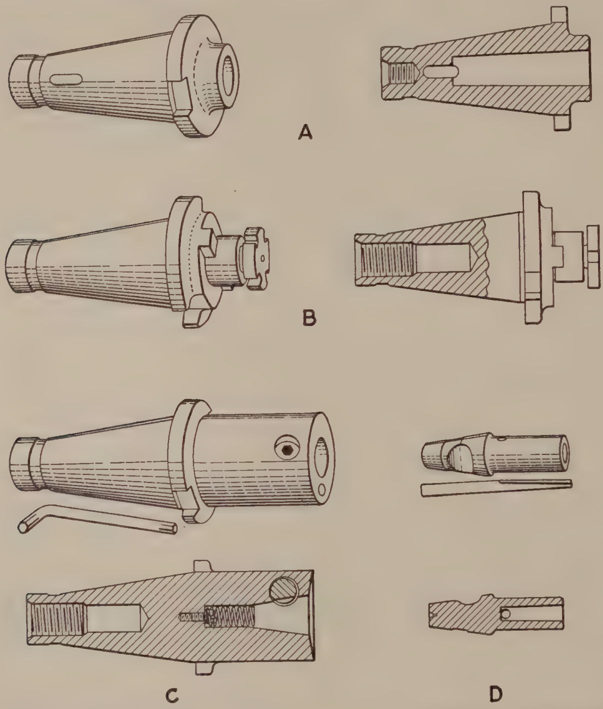


FIG. 214.—Examples of adapters to fit the standard milling-machine spindle. *A*, for regular taper-shank end mills. *B*, for shell end mills. *C*, for the smaller Brown & Sharpe cam-lock collets as in *D* or for end mills, etc., having cam-lock taper shanks.

FIG. 215.—Whitney keyway cutter chuck. The front end of the arbor is slightly tapered for a short distance and then threaded, and the hole in the nut is correspondingly tapered and threaded. The end of the arbor is split by three equally spaced slots, and tightening the nut serves to grip the shank of the cutter. This type of chuck is often called a spring chuck.

194. Holding Face-milling Cutters.—The larger end-milling cutters are generally known as face-milling cutters. Face-

milling cutters are mounted directly on the end of the milling-machine spindle, securely held by four bolts in such a manner as to locate the cutter accurately and drive it positively and also to make its removal easy. (Refer to Fig. 180.)

195. Screw-on Cutters and Arbors.—Many of the small cutters such as corner-rounding, convex and concave cutters, and cutters for fluting the smaller sizes of end mills, reamers, counterbores, etc., are often of the form of screw-on cutters. The hole is tapped ⅜–16 or ½–16 and the screw arbor (Fig. 216) is threaded on the end to receive the cutter. In order that the cutter will not loosen and come off the arbor during the cut and thus spoil the work, right-hand cutters (see paragraph 186) have right-hand threads and left-hand cutters have left-hand threads.

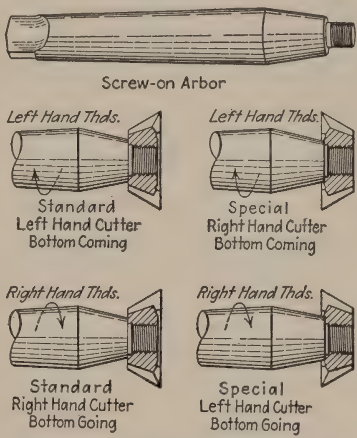


FIG. 216.—Screw-on arbor and cutters. To avoid confusion when making or ordering right-hand or left-hand threads in right-hand or left-hand cutters, the four applications, two *standard*, and two *special*, must be considered.

Screw-on cutter arbors are usually made either with No. 7 Brown and Sharpe taper shanks and fit into a collet, or with a cam-lock shank fitting an adapter.

Questions on Milling Cutters

Obtain from the toolroom an example of each of the following milling cutters: Spiral mill, metal-slitting saw or slotting cutter, side mill, angular cutter, and end mill.

1. How large in diameter is this spiral mill? How long is the cutter? How wide is the face?

2. Roll the cutter fairly hard on a piece of paper and measure the angle of the tooth with the axis of the cutter. What is the angle of the spiral of the cutter?

3. What is a spiral milling cutter used for?

4. What is the advantage of the spiral tooth?

5. Lay the edge of a scale across the face of the slotting cutter. Why is it not made straight? Is the end of the spiral mill straight? Why?

6. What is meant by a plain milling cutter? Is the slotting cutter a plain milling cutter? Explain. Is the spiral mill a plain milling cutter?

7. What is the general shape of the tooth of the slotting cutter? Of the spiral mill?

8. How much clearance is given the cutting edges of these cutters? Why not more? Why not less?

9. Lay the edge of a scale across the face of the side mill, and look under it. Have the side teeth any other clearance than the tooth clearance? Give reason.

10. Is the length of the hub equal to the width (thickness) of the side mill?

11. If it is desired to use a pair of these side mills for straddle milling will a collar be used which is the same thickness or length as the distance required between cutting surfaces? What thickness will be used?

12. Why should you think it advantageous to have thin metal collars or "washers" or "spacers" for obtaining the correct distance between straddle mills?

13. Do the side teeth of a side mill cut when straddle-milling? Of what use are they?

14. Could a side mill be used efficiently for cutting on one side only? Give reason?

15. What is meant by an interlocking cutter? How is such a cutter advantageous when milling slots of an exact width?

16. Examine the angular cutter. What angle is it? Is it so marked?

17. Is it a right-hand or a left-hand cutter? Is it so marked?

18. State how you can select a right-hand or left-hand cutter that is not marked.

19. What is a double-angle cutter? What do you mean by a 90-deg. cutter? 60-deg. cutter?

20. What is the shape of a cutter for milling spirals? What is the difference between a 48–12-deg. cutter and a 53–12-deg. cutter?

21. What are the general characteristics of an end mill?

22. What is the largest size of solid end mill usually made? Why?

23. How are end mills of the larger sizes made? What is the advantage?

24. What is the cutter of still larger diameter with teeth on the face called?

25. When is an end mill useful for plain milling?

26. Is it advantageous to have the peripheral teeth of an end mill 1¼ in. in diameter cut spirally? Of an end mill ⅝ in. in diameter?

27. What is the reason you cannot use an end mill as a drill?

28. What advantage has a cam-rock adapter?

29. What is a cotter mill? What is the advantage of having only two teeth?

30. How do you distinguish a right-hand end mill?

31. Of what kind of material is the body of an inserted-tooth cutter made? Of what kind of steel are the teeth made? What is the difference in the price of these materials?

32. If one tooth of a solid cutter breaks, does it affect the efficiency of the cutter? Can a solid cutter with a broken tooth be repaired? How may such a repair be made on an inserted-tooth cutter?

33. Can a worn-out solid cutter be remade to original size and shape? How can an inserted-tooth cutter be remade? What would be the cost of remaking compared to a new solid cutter?

34. Is it easy to harden a large solid cutter? Can you guarantee it will not crack?

35. Is it easy to harden teeth for an inserted cutter? Suppose one or two of the teeth are cracked what would you do?

36. How are you able to shim under the teeth of an inserted cutter if necessary? When may this be advisable?

37. State all the advantages you believe an inserted-tooth cutter has.

38. Obtain from the toolroom a formed cutter: a gear-tooth cutter will do. What is meant by a formed cutter?

39. Can you explain how, in the process of making the cutter, the teeth of the cutter are formed to the irregular shape and "backed off" at the same time?

40. When the cutter is being formed and relieved (backed off), the forming tool is held exactly on center. Why is this necessary?

41. What part of the formed cutter is ground when necessary to sharpen the cutting edge?

42. How should the formed cutter be ground to preserve the original shape of the cutting edge? Why?

43. When should a formed cutter be ground? Why? How much of the tooth may be ground without destroying the original shape of the cutting edge? Why?

44. Why is a double-angle cutter, or a cutter for cutting spiral mills, or a reamer-grooving cutter, usually made with formed teeth rather than with saw teeth?

45. What is a helical cutter? State two advantages that it has.

46. How many reasons can you give for the efficiency of the formed cutter.

47. What is a fly cutter? When is it advantageous to make and use a fly cutter? How is a fly cutter held?

48. When making the fly cutter, what is the object of turning (forming) the cutter with the liner behind it? *Ans.* To give it clearance.

49. The tendency of the manufacturers is to substitute whenever possible for the radial face on the teeth of milling cutters a face having a rake of about 10 deg. Further, since high-speed steel has largely superseded carbon steel for milling cutters, the tendency has been toward coarser teeth. What is the advantage of rake on milling-cutter teeth?

50. What are two advantages of coarse teeth on milling cutters?

51. Are formed milling cutters given a spiral cut? Give reason. Are they given rake? Give reason. Do they have coarse teeth?

52. Why do the longer spiral milling cutters have nicked teeth? How is the nick given clearance? Why is it given clearance?

53. Why is a right-hand spiral out on a left-hand end mill?

54. Why are small-diameter cutters made with shanks?

55. What is the reason for making some cutters screw on a shank?

56. Why does a left-hand screw-on cutter have a left-hand thread?

57. What is a T-slot cutter? Why do you have to remove the central portion of the T slot before using the T-slot cutter?

58. If you go to the toolroom to obtain a milling cutter, how do you specify the cutter you wish?

59. It may be stated that half the life of many cutters is wasted by running when dull. Explain in detail.

60. How many of the various kinds of cutters listed in a catalogue of cutters are you able to find and examine?

CHAPTER X

SPEED, FEED, AND DEPTH OF CUT

196. Introduction.—The output of a machine is dependent among other things upon the efficiency of the cutting tool. To remove a given amount of metal, the cutting tool is efficient only when operated at the proper depth of cut and the proper speed and feed. Therefore in the matter of production the question of cutting speeds and feeds is of extreme importance to the employer. And in the matter of making good, a knowledge of the conditions that enter into the question "What is the right speed, feed, and depth of cut for this job?" is of extreme importance to the progressive machinist.

As the work is fed against the revolving milling cutter each tooth peels off a chip. The amount of metal removed in a given time depends on the width of the cut, the depth of the cut, the thickness of the chip (fine feed or coarse feed) and the speed of the cutting edge through the metal (cutting speed). The width of cut, the depth of cut, the feed, and the speed are all variables. The feed and depth of cut are more or less matters of judgment, and conditions governing them will presently be explained; the cutting speed, however, is governed by practically fixed conditions.

197. Cutting Speed.—As the work is fed against the revolving cutter, the rate at which the chip is cut is the cutting speed. In other words, the cutting speed of a milling cutter is the speed in *feet per minute* of the cutting edge of a tooth as it peels off its chip.

Taking the cut causes friction between the cutter and the work, and friction generates heat. When a cutter is overheated, the temper is destroyed and in many cases the cutter is ruined. The heat generated in cutting any material depends upon the hardness and toughness of the material being cut;

the harder and tougher the metal, the more the heat generated and, therefore, the slower the cutting speed must be.

Because of its peculiar properties, a cutter made of high-speed steel may be run at double the speed (or more) of a carbon-steel cutter without spoiling the temper, consequently the kind of material from which the cutter is made is an important factor in determining the cutting speed.

From the above it will be observed that the cutting speed depends (1) on the kind of material being cut, and (2) the kind of steel from which the cutter is made.

Since milling machines are now built to take the heavier, faster cuts with high-speed-steel cutters, and since these cutters are now practically as cheap to buy as carbon-steel cutters, there seems to be no reason to use carbon-steel cutters except in special cases.

The newer carbide-tipped cutters have great possibilities in certain types of production machines, under very special conditions, such as extremely high speed together with the utmost in power and rigidity for that type. Great care must be exercised in the selection of the proper *grade* of carbide for the particular material. Also, in sharpening, special facilities are required as well as skill and extra carefulness. For general machine-shop milling, the high-speed-steel cutter, properly set for speed, feed, and depth of cut, is more efficient.

Iron castings of different chemical compositions and steels of different manufacture vary so much in their hardness, especially the carbon steels and the alloy steels, that it is impossible to offer a table except for average cutting speeds. What would be a safe speed for one kind of tool steel, for example, would utterly ruin a cutter in a short time on another kind of tool steel. The *average* cutting speeds used in machine-shop practice when machining with high-speed-steel cutting tools are:

70 ft. per min. for tool steel.
90 ft. per min. for machine steel.
90 ft. per min. for cast iron.
200 ft. per min. for brass.

About half the above for carbon-steel cutters.

It is advisable to start with a comparatively slow speed and advance this speed from time to time, if it is found possible to do so without stopping too often to sharpen (or change) the cutter.

198. Cutting-speed Calculations.—The cutting speed of a milling cutter is the speed in *feet per minute* of a point on the *circumference* of the cutter. The number of revolutions per minute necessary to give the required cutting speed depends on the circumference of the cutter. Naturally, for a given cutting speed, the smaller the cutter the faster it must run.

If the circumference of a cutter is 1 ft. and a speed of 40 ft. per min., is required it will take 40 r.p.m. If the circumference were ½ ft., it would take 80 r.p.m. In either case it is the cutting speed divided by the *circumference in feet* of the cutter.

Now in machine-shop practice, the circumference of the work, milling cutters, drills, etc., is never given, the *diameter* is used to express the size, and further diameters are expressed in *inches*. To find the *circumference in feet* of a cutter whose *diameter in inches* is known, multiply the diameter by 3.14 to get the circumference in inches and divide the product by 12 to reduce to feet. The diameter multiplied by 3.14 and this divided by 12 is equal to 0.26 times the diameter ($3.14 \div 12 = 0.26$). Instead of multiplying the diameter by 3.14 and dividing by 12 in every problem it is exactly the same, and much quicker, to multiply the diameter by 0.26. Further, since 0.26 is so nearly ¼ it may be stated that for all practical purposes the revolutions per minute may be calculated by the following:

Rule.—To obtain the revolutions per minute necessary to give the required cutting speed, divide one fourth of the diameter into the cutting speed.

Formula:

$$\text{R.p.m.} = \frac{CS}{0.25D}$$

Example.—It is desired to mill a piece of machine steel at a speed of substantially 35 ft. per min. with a cutter 2 in. in

diameter. What number of revolutions per minute of the cutter is necessary?

$$\textit{Solution:}\ \text{R.p.m.} = \frac{35}{0.25 \times 2} = \frac{35}{0.5} = 70 \text{ r.p.m.}$$

Set the spindle speed to as near 70 r.p.m. as possible.

MILLING MACHINE FEEDS

199. Definitions of Feed.—(1) Theoretically the feed of a milling cutter is the thickness of the chip per tooth of the cutter, that is, the distance the work advances against each succeeding tooth of the cutter. (2) In cone-driven machines the amount of feed is dependent on the spindle speed and is often rated as the distance the table moves per revolution of the spindle. (3) In milling machines having a constant-speed drive, the feed mechanism is usually independent of the number of revolutions of the cutter, and in these machines the feeds are arranged to move the table a certain distance per minute. For this reason it is now quite proper to speak of the milling machine feed as so much per minute, as 1-in. feed, or 10-in. feed, etc., meaning that the table feeds that distance in 1 min. The particular definition of feed is unimportant, the question is one of *proper amount.*

200. Conditions Governing the Amount of Feed.—The problem of proper milling machine feeds offers one of the most interesting and one of the least understood questions in machine-tool operation. There are so many conditions that enter into the question of feeds, that hard and fast rules are impossible. The depth of cut and the width of cut, also whether it is a roughing cut or a finishing cut, in other words, the amount of metal to be removed and the appearance desired are factors. Further, the diameter of the cutter; the number of teeth in the cutter; the proportion of thickness to the diameter; the speed at which the cutter is revolving; the way in which the cutter is held; the power and rigidity of the machine; and the rigidity of the work are all factors which must be taken into consideration in obtaining efficient feed.

201. Analysis of Cutting-feed Conditions.—First, it will be understood that in any operation of cutting metal a considerable force is exerted against the piece being cut and equally against the cutter itself; and that the amount of metal removed (feed and depth of cut) is in proportion to this force. Therefore, the proper depth of the cut and the proper amount of feed depend to a certain extent on what the other is, and in addition, both depend on the power and rigidity of the machine itself.

Second, the correct depth of cut and feed depend on the strength of the cutter and the rigidity with which it is held, and the strength of the work and the manner in which it is held. For example, a slender end mill or a thin slitting cutter cannot be given heavy duty; neither should a frail piece of work or a piece held in such a manner that it may spring or bend be given a heavy cut or feed.

Third, the teeth of the coarse-tooth cutter are proportionately stronger than the finer teeth, the chips wash out more readily and the cutting lubricant keeps the cutting edge cooler. For these reasons a heavier chip may be taken with a coarse-tooth cutter.

Fourth, while the coarse feed removes metal faster, the appearance and accuracy of the surface are not as good as is desirable for finished work, therefore, a finer feed is used for finishing.

An example will serve to show the action of a milling cutter. A cutter 3 in. in diameter cutting 35 ft. per min. will make 45 r.p.m. [$35 \div (3 \times 0.26) = 45$]. If this cutter has 12 teeth, then 12 chips will be cut each revolution; and 45 multiplied by 12 equals 540 chips per minute. If the feed is 6 in. per min. and 540 chips are cut per minute, each chip is 0.011 thick. This is theoretical, no milling cutter runs exactly true, but even so, probably no chip will be over $\frac{1}{64}$ in. thick.

In ordinary milling practice, when using a fair-sized carbon-steel formed cutter on machine steel, with a good flow of cutting compound, a feed of 4 or 5 in. per min. is not excessive. With a coarse-tooth spiral cutter 6 or 8 in. per

min. is not too much to try and may probably be increased. Since cast iron must be cut dry, the feed is reduced about one third. High-speed-steel cutters running at about double the speed of carbon-steel cutters will stand up well under practically double the feeds (*in inches per minute*) of the carbon-steel cutters.

The general tendency is to *overspeed* and *underfeed* a milling cutter. The reason for most of the too quickly dulled cutters is too much speed, and rarely if ever too much feed. It will be well for the beginner to go fairly slow at the start and avoid spoiling the cutter or work or possibly both, but to keep right on the job with the idea of advancing the speed or feed as much as possible with due regard to the time it takes to sharpen the cutter.

202. The Depth of Cut.—On most work no more than two cuts are required—a roughing cut and a finishing cut. If it happens that two or more cuts are necessary the rule is to take, for the roughing cuts, a coarse feed and about all the depth of cut the machine, cutter, and work will stand.

As in shaper or planer work care must be taken when milling cast iron that the edges at the end of the cut are not broken away below the finished surface. Milling fixtures, special vise jaws, etc., for manufacturing are designed to back up the metal at this point, thus overcoming the tendency of the corners to break off, but in many special jobs it may be necessary to feed carefully, by hand, toward the end of the cut.

203. The Finishing Cut.—Remember that attention to the slogan "keep cutters sharp" is one of the main factors in good milling; bear in mind that a surface that has been milled with a good sharp cutter is as accurate as a filed and polished surface. Also it is easier and quicker and therefore cheaper to mill to size than to finish by polishing.

When it is advisable to make two cuts, a roughing cut and a finishing cut, leave at least $\frac{1}{64}$ in. for the finishing cut. In any machine a cutting tool will do better work and last longer if the edge has a chance to get under the chip, where it has less tendency to rub.

There is always spring in every milling operation. If the feed is stopped while the cutter revolves on the work, the surface will be defaced by an undercut. *Do not throw out the feed on a finishing cut.*

For the same reason as above if a cut just made is run back under a revolving cutter, the work will be marked each revolution of the cutter. Stop the cutter before running back or else lower the work a trifle.

No milling cutter runs exactly true, and consequently some few teeth do a major share of the cutting. It may be practicable, especially when finishing, to give the cutter part of a turn on the arbor; this often serves to bring the sharper teeth into play.

204. Lubricating the Cutter.—A lubricant should always be used when milling steel or wrought metals. It serves to wash away the chips, produce a better finish, keep the cutter cool, and give a longer life to the cutting edge. A good quality of lard oil is an excellent cutting lubricant. There are, however, several specially prepared cutting compounds (soluble oils) on the market which are cheaper than lard oil and for most operations serve the purpose. Provision is made in all milling machines to save the lard oil or cutting compound and use it over and over again. The manufacturing milling machines are equipped with a pump to effect the circulation and provide a steady stream of the size and force desired. The smaller machines and the universal machines are not usually equipped with pumps, so the cutting compound is held in a small can from which it is allowed to drop on the cutter through a pipe. In any event the cutting compound should be used freely but should not be wasted, that is, should not be allowed to drench the machine and the floor. Remember cast iron is always machined dry (see paragraph 31, page 35).

205. Direction of Cutter and Feed.—It is usually considered better practice to feed the work against the cutter as shown at *a*, Fig. 217 rather than with cutter as shown at *b*. There are two good reasons for this: When the work is fed in the opposite direction to that in which the cutter revolves, the teeth do not

come in contact with the scale, and also the backlash in the feed screw is taken up against the force of the cut preventing any tendency of the cutter to "dig."

NOTE.—As an exception to the above, when cutting off stock and when milling comparatively deep or fairly long slots, there is less tendency for the cutter to crowd sidewise, thus making a crooked cut and possibly breaking the cutter, if the slotting cutter is operated as shown at *b*, Fig. 217.

The direction of the cutter with regard to the manner in which the work is held is important. (1) The arrangement

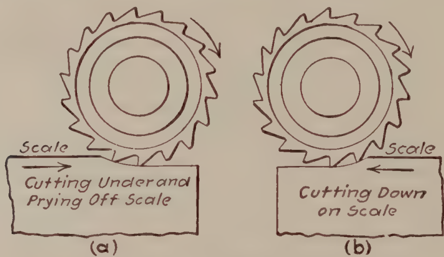


FIG. 217.

should be such that any tendency of the work to spring will be in a direction away from the cutter. (2) The arrangement should be such that there will be no tendency to loosen or displace the work.

Caution.—To run a cutter "backward" will break the teeth. Be very sure the cutter is mounted on the arbor to revolve in the proper direction and *that the machine spindle is arranged to revolve in that direction.*

Questions on Speed, Feed, and Depth of Cut

1. What conditions govern the cutting speed of a milling cutter?

2. What is the difference between revolutions per minute and feet per minute?

3. What is the average cutting speed for the different metals used in machine construction when using carbon-steel cutting tools?

4. How many revolutions per minute should a carbon-steel milling cutter 3 in. in diameter be run to cut machine steel? Tool steel?

5. What is the formula for calculating revolutions per minute of milling cutters having given the diameter of the cutter and the required cutting speed?

6. Having calculated the revolutions per minute, how do you set the spindle speed? Can you set it exactly right? Give reason.

7. How do you define milling-machine feed?

8. State at least six conditions that govern the amount of feed in milling.

9. How many different rates of table feed may be obtained in the machine you are running?

10. Generally speaking, how much of a chip may be taken in the roughing cut?

11. State three reasons why a dull cutter should not be used.

12. How much should be left for a finishing cut? Why?

13. What would happen if the finished surface is run back under the revolving cutter? How is this avoided.

14. What is the value of cutting lubricant?

15. What is the general rule concerning the direction of the cutter and the feed? What are the reasons? State an exception to this rule.

CHAPTER XI

TYPICAL MILLING SETUPS AND ELEMENTARY OPERATIONS

HOLDING THE WORK

206. Various Methods of Holding Work.—Several T slots, running the length of the worktable, finished to a standard width, and exactly parallel with the travel of the table, are provided for the purpose of locating and clamping the work itself, or any device for holding the work.

The following list of methods of holding work in the milling machine will serve to give some idea of the adaptability of the machine and also of its value in manufacturing and in general machine-shop work and toolmaking. The figures referred to in this list are mostly for the purpose of illustrating other details, but since they show also some of the methods of holding work it may prove helpful to refer to them in this connection.

The work may be held in a special fixture (Figs. 179 and 186).

It may be clamped directly to the table (Fig. 181).

It may be fastened to an angle plate or similar tool which is clamped to the table.

It may be held in a vise (Figs. 178 and 183).

It may be held between the centers of the index head and footstock (Figs. 170 and 184).

If provided with a taper shank, it may be held in the index-head spindle or in a collet which fits the index-head spindle.

It may be held in a chuck which screws on the index-head spindle (Fig. 175) or in a drill chuck or a special chuck the shank of which fits the taper hole in the head spindle.

It may be held on a faceplate which screws on the index-head spindle.

When the work is held by means of the index centers, using any of the last four methods suggested, it is usually for the purpose of *indexing*. The index head and the methods of indexing are explained in Chap. XII.

207. Milling-machine Fixtures.—In manufacturing, where large numbers of pieces are to be milled alike, it is customary to hold the work in fixtures. A milling fixture is a special device for accurately locating and securely holding one or more pieces while the desired cut is being made. It is usually clamped to the table (see Figs. 179 and 186).

Fixtures are made to hold work for various operations in any of the standard machine tools but are used most in milling-machine work. The purpose of a fixture is to make it easy for the operator to locate the work quickly and accurately, support it properly, and hold it securely.

In addition to the locating, supporting, and clamping features of the fixture, setting pieces or gauge points, or both, are often so valuable as to be almost necessary. That is, when a fixture is used on a planer, on a milling machine, or elsewhere, if certain surfaces of the fixture corresponding to the important surfaces to be machined on the work are provided as permanent features of the fixture, they will save a great deal of time and trouble in setting the cutting tools and in gauging the work. To avoid any tendency of cutting into the setting piece it may be made somewhat undersize and a suitable thickness gauge or size block used when setting the cutter.

Fixtures vary in design all the way from special parallel pieces, suitable blocks, or specially shaped vise jaws, each possibly provided with locating pins, to very expensive complicated mechanical devices. The use of fixtures[1] is more particularly manufacturing work, and the making of fixtures is toolmaking. A very important part of the "tooling" of a production shop is the design and making of fixtures. It

[1] For illustrations and descriptions of typical milling fixtures, the reader is referred to "Practical Treatise on Milling and Milling Machines," Brown & Sharpe Manufacturing Co., Providence, R. I.; "A Treatise on Milling and Milling Machines," The Cincinnati Milling Machine Co., Cincinnati, Ohio.

is the sort of work that calls for ingenuity plus machine-shop training.

208. Clamping Work to the Table.—Certain principles of clamping work to the table, to an angle plate, etc., have been explained in the chapter on Planer Work beginning on page 171. It is suggested that the student refer to these pages.

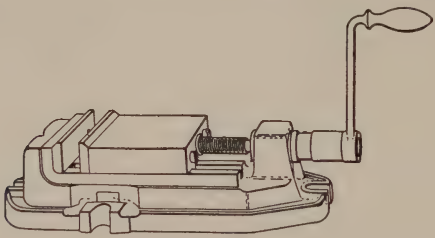


FIG. 218.—Plain vise.

209. Holding in a Vise.—For holding a large variety of work a vise may be most advantageously used. Vises are made in many sizes to correspond with the size of machine on which they are used, or if desired, to accommodate a wide range of work on the same machine. There are three distinct kinds of vises: the *plain* vise, the *swivel* vise, and the *universal* vise.

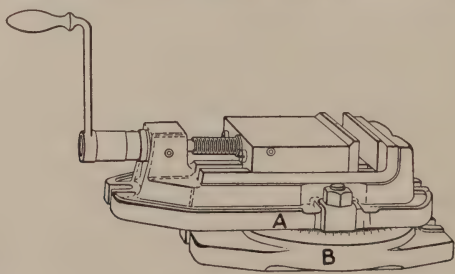


FIG. 219.—Swivel vise. The vise *A* may be removed from the base *B* and used as a plain vise.

The Plain Vise (Fig. 218).—For milling cuts parallel to the length of the work or at right angles to the length, the plain vise is best. It is simple and substantial and holds the work close to the table. Key slots at right angles and removable keys are provided, by means of which the vise may be quickly

set either exactly lengthwise or crosswise on the table. A very efficient holding device can be cheaply made if special jaws are provided having the necessary locating pins or stop pins, and possibly having a profile to correspond with the outline of the cut (see Fig. 224).

The Swivel Vise.—If the keys are removed from the bottom of a plain vise, it may be set in any position on the table by means of a protractor. A *swivel vise* (Fig. 219) is, however, much more convenient. This vise may be swiveled to any angle and rigidly clamped on its base, the position being indicated by graduations in degrees. It is a very useful all-around vise but is not so rigid as a plain vise.

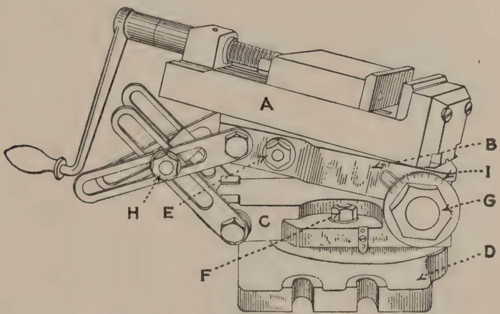


FIG. 220.—Universal vise. The vise proper, A, may be swivelled on the upper part B of the hinged knee. (First loosen E.) The lower part C of the knee may be swivelled on the base D. (First loosen binding bolts F.) The upper part of the hinged knee may be set at any angle from a horizontal to a vertical position, and clamped by tightening the nut G on the bolt which forms the hinge pin, and the bolt H at the joint in the braces. Graduations in degrees on dial I indicate the angular setting of the hinged knee. Graduations in degrees are provided also to indicate the position of A on B and the position of C on D.

The Universal Vise (Fig. 220).—The vise contains two complete circle swivels separated by an adjustable angle plate or "hinged knee," all three of which are graduated to indicate the position in degrees. It may be set and rigidly clamped at any angle with the table or the machine spindle. To one who is familar with its advantages, this vise seems almost indispensable in toolmaking and model work. It is not meant for heavy milling.

SETTING UP THE MILLING MACHINE

210. Aligning and Squaring the Holding Tools and Work.—It is not always practicable to use the keys for locating the plain vise; perhaps the keys may be too large or too small or not in the position desired. Moreover, it is not always wise to depend on the graduations of the swivel vise for accurate setting. Further, it is very often necessary to align a surface or check a setup by other means than either the key or the swivel graduations, for example, an angle plate or a similar

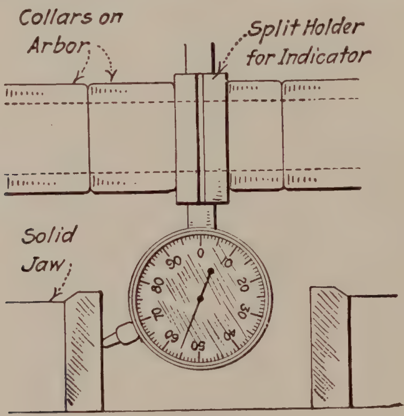


FIG. 221.

tool or some previously finished surface of the work. One of the best ways to set the fixed vise jaw, or other surface to be aligned, exactly parallel with the direction of the cut, or exactly at right angles to it, is by means of an indicator as shown in Fig. 221. First set the surface to be aligned in position as nearly as may be judged, then having the contact point of the indicator against this surface, tighten the body or shank of the indicator between two collars on the arbor, and moving the table lengthwise or crosswise as the case may be, note the movement of the indicator needle and adjust accordingly.

If an indicator is not available, a square may be used for setting at right angles by placing the beam of the square

against the finished face of the column, and the blade along the vise jaw or other surface to be squared (Fig. 222).

For the reason that feeling is at times more nearly accurate than seeing, feelers of tissue paper are often placed between

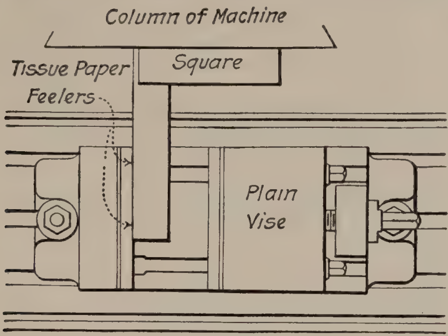


FIG. 222.

the surface to be tested and the blade of the square as shown in the figure. If about the same force is required to pull either feeler, the surface is assumed to be square.

Parallels may be used to set the angle plate parallel with the cut. Clamp the angle plate fairly tight in its approximate

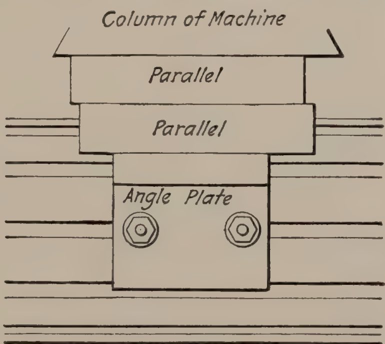


FIG. 223.

position and then lightly squeeze one or more clean parallels between it and the face of the column (Fig. 223). This will bring the surface of the angle plate in line with the edge of the parallel; then clamp the angle plate securely.

A vise may be aligned in a similar manner by clamping a parallel in the vise so that it projects somewhat above the jaws and lightly squeezing one or more other parallels between it and the column. If for any reason the table of a universal milling machine has been set at any angle, it may be accurately reset by using a parallel as explained above between the side of the table and the column. As a matter of fact it will be wise to set the table exactly in this manner before the vise or angle plate is set. Do not depend on the swivel graduations for extreme accuracy.

The above methods are the most accurate methods, but if the milling arbor runs true or very nearly true, the vise or

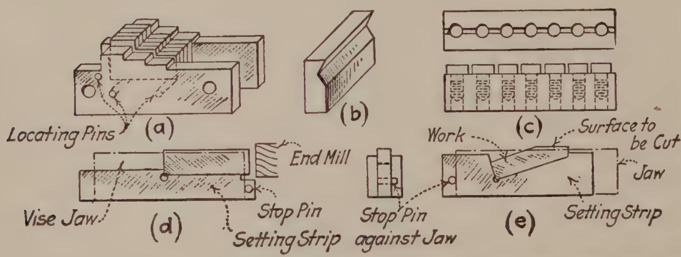


FIG. 224.—Sketches to show the use of special jaws and setting strips: (*a*) several thin pieces in special jaws; (*b*) special jaw for holding a cylindrical piece; (*c*) "false" jaws for slotting screws; (*d*) and (*e*) setting strips.

angle plate may be set parallel or square enough for the average job by (1) arranging the face to be set *parallel* against the arbor or (2) arranging the face to be set *square* against the blade of a square, the beam of which is held against the arbor.

211. Special Vise Jaws.—In many cases a vise may be quickly and cheaply transformed into an efficient "fixture" by substituting special jaws for the regular jaws. Special jaws may be shaped to the general contour to be milled, being a trifle smaller for clearance. A pair of vise jaws made in this way is shown in *a*, Fig. 224. The thin pieces, in addition to being firmly held, are "backed up" by the jaws over practically the entire surface and are thus kept from bending under the pressure of the cut.

It is unnecessary to remove the regular jaws when "false jaws," as for example *c*, Fig. 224, are used; these may be clamped between the regular jaws. False jaws are frequently used for slotting screws; they work very well even when some of the screws are a trifle small, provided the cutter is central and the screw is not too short.

Very often a setting strip in the vise may serve to accurately locate duplicate pieces. Such strips *d* and *e*, Fig. 224, may be very quickly made of a suitable piece of cold-rolled steel.

GENERAL PRECAUTIONS TO BE OBSERVED WHEN SETTING UP

212. The Milling-machine Setup—Introduction.—Setting up a milling job is considerably more than half the battle; taking the cut is comparatively simple. Know what is wanted, get ready thoughtfully and go ahead carefully. Mistakes will sometimes occur. The person who never makes a mistake never accomplishes much in this world. The mistakes of one who is attentive, thoughtful and "on the job" are excusable. The spoiled work or cutter, the delayed production, the broken machine due to the blundering stupidity of the lazy indifferent individual are results of mistakes that are inexcusable.

Form the habit of having the machine and work *clean*. Before putting the vise or fixture or any attachment on the worktable, clean the seating surfaces of all chips and burrs. Also, if any chips or burrs cling to the work, or to the jaws of the vise or fixture, the work cannot be properly seated and will be inaccurate. Keeping the work and holding tools clean is one of the most important points in milling-machine work.

Form habits of orderliness around the machine. Have a washer and nut on each bolt, and all of the bolts where they belong; have the miscellaneous tools such as stops, center rests and gears clean and in their place, likewise the arbors, collars, and collets. When several pieces are to be milled, arrange them in an orderly way—those already milled and those to be milled.

Above all, form the habit of carefulness. *Keep your hands away from the revolving cutter.* If necessary, when setting a revolving cutter close to the work, to hold a piece of paper between the cutter and the work, hold the paper in *front* never in back of the cutter.

213. Setup of the Work.—The result of vibration in any machine tool is a poor product and inefficient production; vibration dulls tools more quickly than hard work. The most important single characteristic of a first-class milling machine is its rigidity. In no other machine, except possibly the grinding machine, is the effect of vibration as apparent, and probably in no machine is the expense of sharpening the cutting tools as great.

Have the work held as rigidly as possible and when necessary supported by a jack, or suitable packing blocks and shims. In any case, the work must be held securely and rigidly; it must not be sprung in clamping or allowed to spring under the pressure of the cut.

Have the table as close to the column as the job will permit.

While the setup is being made, the clamping screws for both the knee and the saddle should be slightly loosened, but before starting the cut, except, of course, when a vertical or a lateral feed is to be used, *both clamps should be tightened.*

When an end mill or face mill is used, set the cutter first and then set the work to correspond to the position of the cutter. In this case, the position of the work is determined by the distance the cutter projects, and the setup is usually as rigid as necessary. When, however, a cutter is to be mounted on an arbor, set the work before setting the cutter. First run the table in fairly close to the column of the machine for sake of rigidity. Next set the work in position in whatever holding device is to be used. Then set the collars and the cutter, with the cutter in its proper position, and the outboard bearing collar (*B*, Fig. 211, page 232) as close to the cutter as practicable.

Milling chips are especially troublesome. If chips or burrs stick to the work, and are pinched between the work

and the vise jaw, they will become imbedded in the work and spoil the surface. The care taken to clean the seating surfaces of the vise or table or fixture will make for speed and accuracy. *Be sure all clamping seats and surfaces are clean.*

214. Selecting the Cutter.—Get the cutter that is the right shape and size and be sure it is sharp. Never use a dull cutter. Considerable time may be wasted by using a cutter larger in diameter than is necessary. Referring to Fig. 225, suppose it is required to finish the surface *X*; the proper cutter to use is an end mill of about the diameter of *A*. In the figure, *B*

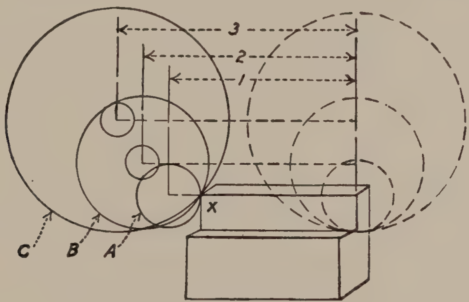


Fig. 225.

shows the diameter of the smallest plain milling cutter that can be used and allow the arbor and collars to pass over the work, while *C* represents a cutter much larger than necessary. From a comparison of the feeding distances, (1), (2), and (3), it will be apparent that the cutter of smaller diameter will take less time.

215. Setting the Cutter.—1. Be sure the taper hole in the spindle or collet is clean—free from chips and dirt, and wiped dry. Likewise the taper shank of the arbor or collet or cutter. *An oily taper will not hold*, and many jobs have been spoiled by reason of the operator's neglect of this important point.

2. If the arbor is held and driven by a taper shank, with no draw-in bolt, it must be *hammered home* with a babbitt hammer. It must be *tight* in the spindle.

3. If the arbor or collet is held by a draw-in bolt, have everything clean and be sure the arbor is tight.

4. Many of the taper-shank end mills, etc., must be driven in the collets with a babbitt hammer or a suitable copper rod. In order not to break the small end mills, judgment must be used; they are quite brittle and will break if struck carelessly.

5. Clean the arbor and the collars, also the sides of the cutter.

6. To run a cutter "backward" will break the teeth. Be sure the cutter is mounted on the arbor to revolve in the right direction, and that the machine spindle is arranged to run in that direction.

7. Have the cutter as close to the spindle, and the outboard bearing as close to the cutter, as the work will permit.

8. To allow the arbor nut to tighten when only partway on will strain the threads of both nut and arbor. Select such collars as will allow the nut to screw on practically its full length.

216. Setting the Speed and Feed.—Among the most important considerations of any setup are the cutting speed and feed. These must not be left to chance nor to mere guesswork. The conditions that obtain for the given job must be considered even by the experienced machinist. He usually knows what to do under the given conditions.

Quality of work depends upon the sharp cutter, the right method of holding the work, the accuracy of measurement, etc., but, these things being right, *quantity* depends upon the speed, feed, and depth of cut. Do not forget that doing a job well involves both quality and quantity.

Calculate the revolutions per minute for the proper cutting speed for the given cutter and the given job; judge the amount of feed and the depth of cut according to reason. Remember the tendency to feed too slow. Remember also that in many jobs one cut is enough; two cuts (roughing and finishing) are necessary only (1) when a considerable amount of metal must be removed, (2) when there is unusual tendency to spring, and (3) when a particularly accurate result or a particularly excellent finish is desired.

217. Setting the Feed Trip.—When several pieces are to be milled and any of the automatic feeds are used the feed-trip

dog is set to operate at the desired point—usually just as the work feeds from under the cutter. If no stop for the end of the work being milled is provided, either on the vise jaw or other holding or locating appliance, care must be taken, when placing the successive pieces, to place them in the same position as the first piece, otherwise the feed may stop before the cut is finished and this will produce an "undercut." In certain operations, however, the feed must be tripped during the cut, and such a case requires attention, when the feed trips, to avoid an undercut.

218. Concerning an Undercut.—No matter how carefully a cutter is ground, it will not run exactly true in operation, especially a cutter mounted on an arbor. And no matter how well it may be supported, there is always a certain tendency to spring under the cutting pressure. Owing to these conditions, if the feed is thrown out during the cut, the cutter will mill a trifle deeper at this point. On a finishing cut this is a serious fault because an undercut only 0.002 or 0.003 in. deep is very noticeable, and unless the table is raised, the undercut will not be removed even if it is run under the cutter a dozen times. If necessary to stop during the finishing cut, stop the cutter and *do not* throw out the feed.

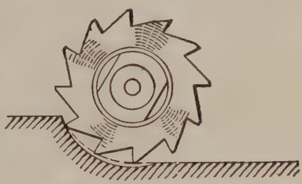


Fig. 226.—An undercut.

The undercut is much more pronounced if the cutter is caused suddenly to take a much heavier cut. This is illustrated in Fig. 226. When finishing such a surface (against a shoulder), the best method is to set the *automatic feed trip* to disengage the feed about $\frac{1}{16}$ in. before the heavy cut is reached, and to set the *positive stop* for the end of the cut. Just before the automatic feed is tripped be ready to "catch" the feed, and feed by hand to the positive stop. It may be advisable to lower the table a little as the heavy cut is reached.

The same conditions that cause an undercut will tend to injure a finished surface if the work is run back under the cutter unless (1) the cutter is stopped or (2) the work is lowered a

trifle. For example, suppose as the work is run back the cutter revolves four times, four "trade-marks" will result because every time the cutter revolves one tooth will dig a little into the finished surface.

219. Other Uses of the Positive Stop.—Occasionally, when feeding by hand, it is desired to start or stop a cut at an exact point, and the positive stop is set. There are other times, for example, when milling the grooves in reamers, or similar cuts that "end in the metal," when it is advisable to get a better finish by hand feeding about $\frac{1}{16}$ in. after the power feed is tripped.

Sometimes it is necessary to start a cut by "lifting the work" (by raising the table) into the revolving cutter, and, owing to backlash in the feed screw, the cutter has a tendency to dig in. Setting the positive stop will prevent this.

Be careful to loosen the older-style stop, which is clamped to the table slide bearing, before leaving the machine.

EXAMPLES OF PLAIN MILLING OPERATIONS

220. Milling a Rectangular Piece.—One of the simplest jobs but even so one that calls for close attention to detail is squaring up a rectangular piece as illustrated in Fig. 178. A spiral milling cutter wide enough to cover the broadest surface is used. Select parallels of the proper height so that the work does not project too far above the jaws, tighten the work securely then tap with a babbitt hammer to make sure it is firmly seated. Having set the correct speed, feed, and depth of cut, start the cutter revolving, run the work fairly close to the cutter, then carefully until it touches the cutter, and throw in the feed. Set the feed-trip dog to throw out the feed at the end of the cut. In connection with tripping the feed in milling-machine work the operator must remember to so place the work as to have the end of each succeeding cut in the same relative position as the cut for which the trip was set.

Finishing a rectangular piece in the milling machine differs in no particular respect from planing a similar piece in the

shaper vise or planer vise except in the machine and cutting tool used. The sequence of operations and reasons therefor and the precautions regarding chips, burrs, etc., are the same. The student is referred to the discussion of these things in paragraphs 101 and 107.

221. Squaring the Ends.—The shorter pieces may be squared on the ends with a spiral milling cutter, when "tipped up" in the vise and one finished side squared with the bottom of the vise as explained in shaper work (paragraph 109). The vise jaws should be arranged at right angles to the direction of the cut or the work is likely to move. If the work projects much above the vise jaws, it is likely to spring and chatter;

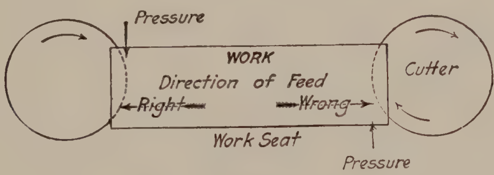


Fig. 227.

consequently most end cuts are made by laying the work flat and allowing it to project from the vise or other holding fixture and finishing with either an end mill or possibly a side mill or for the larger surfaces a face mill. If the work is long enough to project both ends beyond the holding device and there are enough pieces to warrant the setup, a pair of side mills ("straddle mills") may be used to square both ends in one operation. In such a setup an adjustable collar (one part screwing within the other) is very useful, but if such a collar is not available, collars of sheet copper, brass, or steel, or even paper, may be used to obtain the correct dimensions between the cutters. Make the trial cuts on a piece of scrap.

In the operation of "squaring" or "facing," the feed should be arranged if possible to have the pressure of the cut in a direction toward the seat of the work (Fig. 227), otherwise the work may be lifted from its seat and spoiled.

222. Face milling (see Fig. 180) is finishing a surface at right angles to the axis of the cutter. This does not mean that end teeth or side teeth do the cutting. As a matter of fact, the teeth on the periphery do all or nearly all of the cutting when "facing" with an end mill or a face mill or a side mill. The action of the teeth on the end (or side) when they are properly sharpened is a slight scraping or finishing cut. If these teeth are dull or improperly ground the surface produced will be rough and probably gouged here and there.

When face-milling, care must be taken to have the cutter securely in place, and also that there is no end play in the machine spindle.

If it is desired to finish a curved surface of the same radius as the cutter this may be done by feeding parallel to the axis of the cutter. In this case the end teeth do the cutting and the peripheral teeth do the finishing.

223. Cutting a Keyway or Similar Groove.—There are several different milling-machine methods of cutting a keyway in a shaft, namely, with a plain milling cutter, with an end mill, with a cotter mill, with a Whitney (Woodruff system) cutter. Also there are several ways of holding the shaft—in a vise, in V blocks, clamped to the table itself, or between the index centers or in the index-head chuck. In any case care must be taken to make the keyway parallel to the axis of the shaft.

Arrange the worktable and work as close to the column as practicable. The next step is to place the cutter in position. If it is a taper-shank cutter, place in a suitable collet and drive home, carefully, with a brass rod against the end. If a Whitney cutter (Fig. 231) is used, be very sure that it is firmly held in its chuck (spring collet, see Fig. 193). If a slotting cutter mounted on an arbor is to be used, place it on the arbor in approximately the correct position over the work.

Assuming a cutter of the correct width is used, the work must be adjusted until the cutter is central. This is usually called "locating the cutter central" but as a matter of fact it is the work that is located.

224. Locating the Cutter Central.—One method is shown in Fig. 228. Feed the work carefully toward the revolving cutter until the cutter just tears a piece of tissue paper *A*. Then lower the table and feed in the previously calculated distance *D*, using the graduations on the feed screw. If extreme accuracy is desired check the distance, and in any event *beware of the backlash*. If the keyway is to be cut with an end mill or cotter mill get peripheral contact first as in *B*, Fig. 228, then adjust the work an amount equal to the radius of the work plus the radius of the cutter.

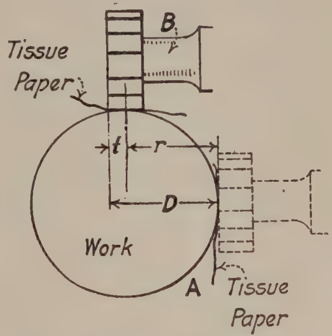


FIG. 228.—The distance *D* equals one-half the thickness of the cutter plus the radius of the work.

A method which may be used if side or end contact is inconvenient (as happens sometimes with a slotting cutter) is shown in Fig. 229. Place a square against the shaft and measure the calculated distance *D* or, as many prefer to do, move the work

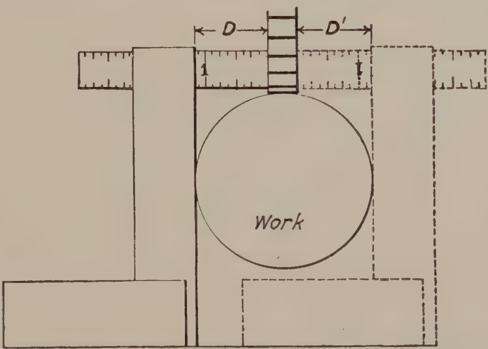


FIG. 229.—The distance *D* equals the radius of the work minus one-half the thickness of the cutter.

until the measurement of *D* and *D′* are equal. The cutter must *not* be revolving.

Still another method that is much used and is fairly accurate is illustrated in Fig. 230. Adjust the work approximately

centrally under the cutter and raise the table until a piece of paper is torn between the revolving cutter and the work, then raise it four or five thousandths more allowing a small "spot" to be cut. Stop the cutter, lower the table and run back a short distance. The small oval "spot" now clearly seen is exactly over the axis of the shaft and the table must be adjusted until the spot appears midway between the sides of the cutter.[1]

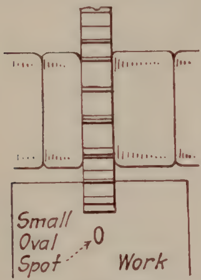


FIG. 230.—Setting the cutter central by the small oval "spot." View is looking down toward the tailstock.

225. Adjusting for Depth of Cut.—When it is desired to make a cut a certain depth (or at a certain distance from a given surface), the work is carefully fed by hand in the necessary direction until a piece of paper held against the given surface is torn by the revolving cutter. (*Use a long piece of paper; keep your fingers away from the revolving cutter.*) This is the starting point for the final adjustment and it is a good plan to set the graduated collar at zero. Then move the work the distance required. The contact position when setting up for cutting the keyway (Fig. 228) is shown at *B*.[2]

It makes no particular difference whether the surface to be gauged from is curved or flat, vertical or horizontal, the above suggestions will apply.

226. "Whitney" Keys.—A line of keys of standard sizes with cutters to correspond which is much used in machine construction is known as the "Whitney" (Woodruff patent).

[1] In a test conducted with a class of ten boys the greatest error made was 0.003 in.

[2] It should be remembered that the depth of keyways and similar grooves is measured from the edge of the slot and consequently the work must be raised a certain amount after it touches the cutter before beginning to cut the prescribed depth of the keyway. Table 9 gives the various amounts to raise the work for sizes of shafts up to 2¼ in. in diameter. For larger sizes consult "American Machinist's Hand Book." For ordinary work, scale measurement from the edge of the keyway is satisfactory.

The keys, (*a*, Fig. 231) are denoted by a number or letter, as the case may be, and the corresponding cutter (*b*) will cut a groove into which the key will fit properly. Frequently a series of two or more keys are used, as shown in *d*.

Cutters are furnished either right hand or left hand as desired. For sizes of cutters and keys see Table 8, page 484.

When setting up, adjust the machine table crosswise until the cutter is central over the shaft (*c*, Fig. 231). Scribe a line (on the first piece) indicating the middle of the key position *d*, and run the work under the cutter until the line

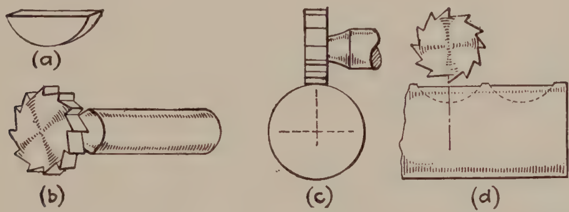


FIG. 231.—(*a*) Whitney key; (*b*) cutter; (*c*) end view of setup; (*d*) side view of setup.

is under the axis of the cutter. Then raise the table to cut the groove to the correct depth, using plenty of cutting compound. It is customary to cut the keyseat to such a depth that the key will project one half its thickness above the shaft. When the correct position of cutter and depth of cut has been determined, set the graduations at zero; if a hand-milling machine is used, set the positive stops.

Succeeding pieces should be located lengthwise by a suitable stop or otherwise to bring the key in the same relative position on each piece.

Questions on Milling a Plane Surface

1. What is a plain milling cutter used for?

2. What is the advantage of the spiral tooth?

3. How much clearance is given the cutting edges of these cutters? Why not more? Why not less?

4. Why is it best to have the table as near the column as possible?

5. What is the proper position on the arbor of the outboard bearing collar? Why?

6. What kind and size of cutter did you select for this job? Why?

7. Why do you have the tapers clean and dry?

8. How do you properly arrange the arbor in the spindle?

9. How far should the nut screw onto the end of the arbor? Why?

10. What difference does it make whether the thread on the arbor is right-hand or left-hand?

11. What direction does the cutter revolve? In what direction does the table feed? Why?

12. What number of revolutions per minute is necessary for the cutter to revolve on this job? Why?

13. How much feed will you use for this job? Why? What are some of the conditions that govern the amount of feed?

14. Do you need parallels on this job? Give reason.

15. How do you seat the work in the vise?

16. When do you use cutting lubricants in milling-machine work?

17. What is the effect if care is not taken to clean away the chips before putting work in the vise: (*a*) on the work; (*b*) on the parallels; (*c*) on the vise?

18. What will be the effect of dirt or chips between the arbor collars?

19. Why should not the revolving cutter be run back over the work?

20. What causes vibration? What are some of the ill effects of vibration?

21. What is the effect of using a dull cutter: (*a*) on the work; (*b*) on the cutter?

22. What is considered a safe cutting speed with a carbon-steel cutter for (1) cast iron, (2) machine steel, (3) tool steel? With a high-speed cutter?

23. What is the characteristic of high-speed steel that makes it valuable for a milling cutter.

24. If the surface to be milled is narrower than half the length of the cutter, what part of the cutter will you set up to use? Why?

25. It is fairly impossible to have a cutter run exactly true. Sometimes on the smaller cutters where a key is not necessary, the cutter may be given part of a turn and cut better. Why?

Questions on Milling a Rectangular Piece

1. What kind of vise is most convenient and adaptable for plain milling?

2. Name and describe three kinds of vises used in milling-machine work.

3. How will you set the vise jaws square with the axis of the cutter?

4. Of what value is the key in the base surface of the plain vise? Why are there two keyways at right angles to each other?

5. How would you set the plain vise with jaws at an angle of 45 deg. with the axis of the cutter?

6. Explain in detail the correct method of setting up this job—the position of the vise, the position of the table with reference to the column, the selection and setting of the arbor, the placing of the cutter and the outboard bearing collar.

7. How will you set the piece in the vise? Are protecting pieces necessary? Give reason.

8. If parallels are necessary, how are they arranged? What size of parallels is advisable? Why?

9. Why do you mill one of the larger surfaces first?

10. What number of revolutions per minute is necessary to give the required cutting speed?

11. What feed is advisable? Why?

12. Will a roughing and finishing cut be necessary? If it is advisable to take a second cut will you rough the piece all over before taking the finish chip on any surface? Give reason.

13. Will you use a cutting lubricant? Give reason.

14. After the first surface has been milled, which is the next surface to cut? Why?

15. What is the purpose of using a narrow strip or a rod between the movable jaw and the work?

16. Which is the third surface? Why? Is the strip or rod necessary? Why?

17. How do the graduations on the screw help in obtaining the proper size?

18. If only two opposite surfaces were to be milled how would you hold the work when milling the second surface?

19. State two ways of holding a rectangular piece to mill the end square.

20. If a short piece is held in one end of the vise, why is it advisable to use a spacing block of equal thickness in the other end?

21. What is meant by a plain vise?

22. Explain the advantage of a swivel vise. Why is it not as sturdy as a plain vise?

23. What features of the universal vise make it possible to take cuts at any angle in both vertical and horizontal planes?

Questions on Face Milling

Get an angle iron and fasten it by means of either bolts or clamps to the table of the milling machine. Do not fasten it too tight until it is exactly square. Proceed to square the face of the angle iron by the most practicable method.

1. If a square is used, against what part of the machine is the beam of the square held? Why? Could it be held against the side of the table?

2. How are pieces of tissue paper used as "feelers?"

3. What is an indicator? With how many kinds of commercially made indicators are you familiar?

4. How is the indicator held between the arbor collars? How do you keep the arbor from moving?

5. When is the piece square by the indicator reading?

6. Can you explain how the graduations of the feed screw may be used for setting the angle iron square?

7 Can these methods of setting an angle iron square be used for setting a vise, or a strip, or a finished face of the work square?

8. If a universal milling machine is used how do you use parallels between the table and the finished face of the column to align the table?

9. What do you understand by the term "face milling?"

10. How does the finish compare with the plain-milling-cutter finish?

11. What will cause a corrugated surface?

12. What will cause a scratched surface?

13. How many degrees clearance has a milling-cutter tooth?

14. Why must extreme care be taken that there is no excessive end play in the spindle bearing?

15. Why should not the cutter be run back over the finished surface?

16. When a number of pieces are being faced, why should the work be tested frequently? When is the best time to test the piece?

17. What is the value of a "stop" against the work?

18. Why is it unnecessary in face milling to feed the work until it is entirely beyond the cutter? When is the cut finished?

19. Why in face milling is it often advisable to remove the work before running the table back?

Questions on Cutting Keyways, Grooves, Etc.

1. If a piece of paper is held between the work and the cutter and the worktable is moved until the revolving cutter just touches the paper, how near is the work to the cutter? Why is this method better than to attempt to just touch the work?

2. Can the work be brought to the side of the slotting cutter, for example, in the same way?

3. Why must you be extremely careful of your hands when working near a milling cutter?

4. Suppose a shaft 1½ in. in diameter is to have a keyway ⅜ in. wide. When the side of the cutter just touches the side of the work how far should the table be moved to bring the same side of the cutter to the correct position to cut the side of the keyway? Why not ¾ in.?

5. How is the shaft clamped to the table? Under what conditions is this a proper method?

6. When may V blocks be used advantageously?

7. When may the index centers be most efficient?

8. What conditions would determine whether the shaft should be held on centers or in the chuck?

9. Of what value is the center rest or jack?

10. Where is the depth of a keyway measured? How usually?

11. What is the reason you cannot use an end mill as a drill?

12. What advantage has an end mill with center cut?

13. What kinds of cutters may be used for cutting keyways?

14. What is the chief advantage of a cotter mill?

15. Are you able to file the end of a piece of drill rod to the form of a cotter mill and produce the correct shape of end teeth and all clearance angles?

16. What are the differences between the end mill and the cotter mill as regards speed, feed, and depth of cut?

17. If a plain milling cutter of the correct thickness is used, why is the smallest diameter that may be used the best?

18. What determines the smallest diameter of cutter that may be used?

19. What would you do if a cutter of the correct thickness was not available?

20. What is the chief fault of a keyway cut with a plain milling cutter?

21. What are some of the advantages of the Whitney (Woodruff) system of keyway cutters and keys?

22. How many sizes of Whitney keys are listed as standard?

CHAPTER XII

THE INDEX HEAD AND INDEXING OPERATIONS

227. Introduction.—Indexing may be defined as the process of causing the work to be moved any desired definite amount on its axis, as for example, the distance from tooth space to tooth space when cutting a gear or from groove to groove when fluting a reamer or a milling cutter. This is accomplished by means of a mechanism contained in the attachment called

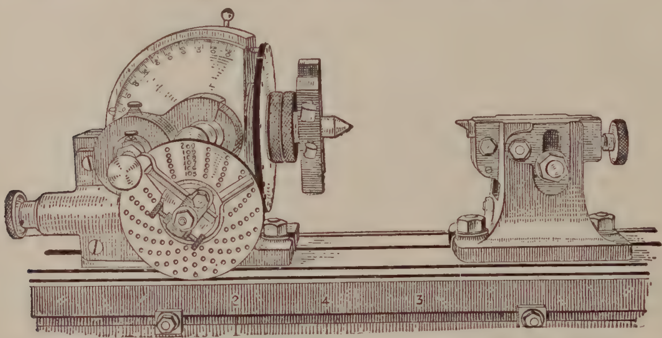


FIG. 232*A*.—Brown & Sharpe index centers. Head on left end of worktable.

the index head. The index head is sometimes called "dividing head" or "spiral head."

The index head and its footstock are together known as the index centers. The practice of several manufacturers is to arrange the index centers on the milling-machine table with the head at the left (Fig. 232*A*), other manufacturers reverse this arrangement (Fig. 233*A*).

228. The Index Head.—The index head (Figs. 232*B* and 233*B*) contains the work spindle and the mechanism (worm and wormwheel, explained in paragraph 230) for obtaining a rotary movement of the spindle when required. *The work spindle* is

provided with a taper hole to receive the live center or the taper shank of other tools, and with a threaded end or "nose" to hold a chuck or any special work-holding device. The spindle has a large bearing surface accurately fitted, and in addition, a clamping device to give greater accuracy and rigidity under a heavy cut. The spindle is carried in the *swiveling block* which is arranged between housings cast integral with the base plate. The swiveling block is so

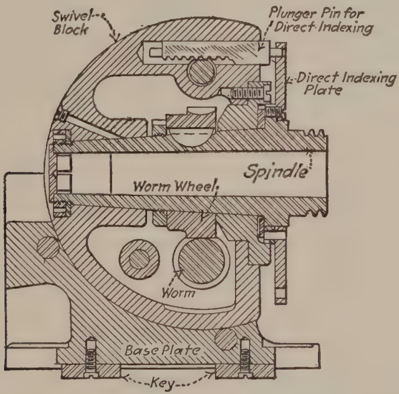


Fig. 232*B*.—Vertical section Brown & Sharpe index head.

constructed that it may be tilted until the spindle is in any desired position from 5 deg. below the horizontal to at least 10 deg. beyond the perpendicular and then clamped rigidly to the base casting (see Figs. 241 and 242). Graduations in half degrees show the angular position. The base is provided with keys which fit the slots in the worktable.

Descriptions of other parts of the index head are given further on in connection with discussions of the mechanisms.

229. The footstock is used for supporting the outer end of pieces being milled. Primarily it is for work held on centers but may be used if necessary for work held in a chuck or otherwise. The footstock center may be adjusted longitudinally, and in addition the block which holds the center and its adjusting screw may be moved vertically. Also it may be tilted out of parallel with the base in order to line with the index

head center when the head is tilted for milling tapered work.

The primary purpose of the mechanism of the head is indexing. There are three different methods of indexing: Simple, direct, and differential. The first two are chiefly used.

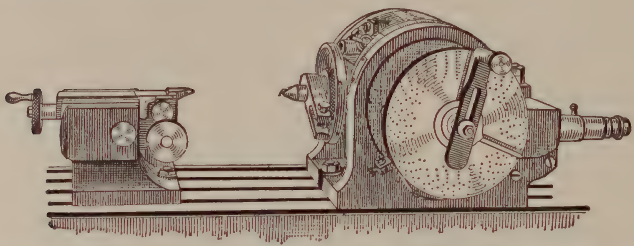


FIG. 233*A*.—Cincinnati index centers. Head on right-hand end of work-table.

230. Simple Indexing.—Simple indexing is accomplished by means of a mechanism (Fig. 234) which consists essentially of a 40-tooth wormwheel fastened to the work spindle, a single-

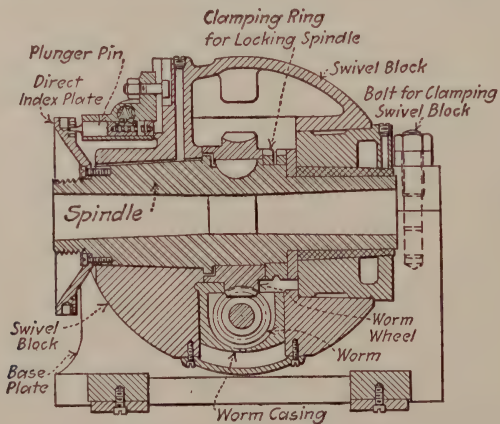


FIG. 233*B*.—Vertical section Cincinnati index head.

cut worm, a crank for turning the wormshaft, and an index plate. Since there are 40 teeth in the wormwheel one turn of the index crank will cause the wormwheel to make $\frac{1}{40}$ of a turn, or in other words, 40 turns of the index crank revolve

the spindle one full turn. Suppose it is required to cut a reamer with 8 equally spaced teeth: If 40 turns of the index crank make one full revolution of the work, then $\frac{1}{8}$ of 40 turns or 5 turns after each cut will space the reamer for 8 teeth. If it is required to space equally for 10 cuts, $\frac{1}{10}$ of 40 turns or 4 turns will give the desired result.

Note, in the examples given, that 40 divided by 8 equals 5 turns and 40 divided by 10 equals 4 turns. As a further

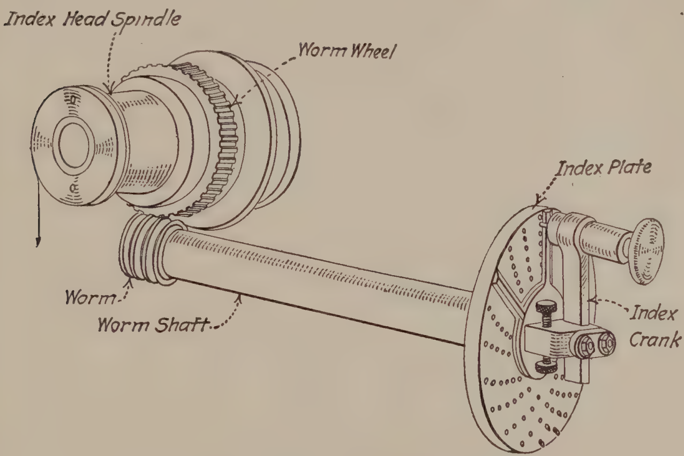


FIG. 234.—Simple indexing mechanism.

example, let it be required to index for 6 equal spaces, then 40 divided by 6 equals $6\frac{2}{3}$ turns, or again, 14 equal spaces are required, then 40 divided by 14 equals $2\frac{6}{7}$ turns.

These examples may be multiplied almost indefinitely and from them may be deduced the following:

Rule for Calculating Turns of Index Crank.—To obtain the number of turns (whole or fractional) of the index crank for one division of any desired number of equal divisions on the work, divide the number of turns for one full revolution of the spindle (usually 40) by the number of equal divisions desired, $40 \div D = T$.

231. Index Plate and Sector.—The fractional parts of a turn involve the use of an index plate and sector. Referring

to Fig. 234, it will be observed that the index pin at the end of the index handle enters a hole in the index plate. If only full turns were used in indexing, one hole only would be necessary, if only turns and half turns were required two holes in opposite sides of the plate would answer, but a great number of different fractional parts of a turn are required for different spacings, and in order to accurately and easily measure them, the index plates and the sector are provided.

The index plate (Fig. 235) is a circular plate, arranged in front of the index handle, provided with a series of six or more circles of equally spaced holes.[1]

With the index plates regularly furnished it is possible to obtain the spacings ordinarily used for gears, clutches, milling cutters, etc. Two examples will illustrate:

First Example.—To mill a hexagon.

Solution.—Using the rule: $\frac{40}{6} = 6\frac{2}{3}$ turns, or six full turns and two thirds of a turn on any circle divisible by 3, for instance, 12 spaces on the 18 circle or 26 spaces on the 39 circle.

Second Example.—To cut a gear of 42 teeth.

Solution.—$\frac{40}{42}$ or $\frac{20}{21}$ turns, that is, 40 spaces on the 42 circle (Cincinnati) or 20 spaces on the 21 circle (Brown & Sharpe).

Referring to Fig. 235, the index crank is adjustable radially (first loosen screw C), so that the index pin may be used in any of the circles of holes in the plate. The index pin is held in the hole by a spring contained in the handle and when the pin is pulled against the force of the spring, out of the hole, the crank may be moved.

The *sector* (Fig. 235) consists of two radial arms S, so constructed that the angle included between them may be changed (first loosening the binding screw B). The use of the sector

[1] The Brown & Sharpe Manufacturing Co. regularly furnish index plates with circles of holes as follows:

Plate 1	15–16–17–18–19–20
Plate 2	21–23–27–29–31–33
Plate 3	37–39–41–43–47–49

For divisions which cannot be obtained with any of these circles differential indexing is used.

obviates the necessity of counting the holes, at each cut, for the fractional part of a turn, and in addition to saving time makes for accuracy. Select a circle divisible by the denominator of the required fraction of a turn (reduced to lowest terms) and bring the beveled edges of the arms of the sector to include the fractional part of the circle desired. In counting the holes in the plate when adjusting the sector *remember it is*

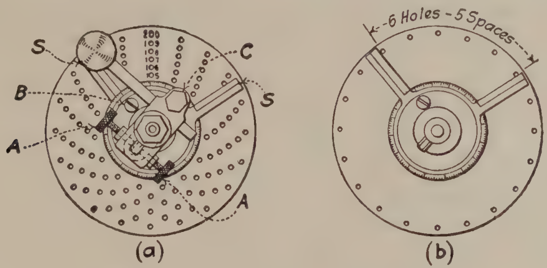


FIG. 235.—Index plate and sector.

really the number of spaces between the holes that gives the desired fractional part of the whole circle. Consider the hole the pin is in as zero. An example is illustrated in *b*, Fig. 235.

When the spindle is not clamped, the index handle should turn easily.

The sector is under spring tension in order that it will remain set. It should, however, be easy to move to the next setting.

The Cincinnati Milling Machine Co. regularly furnish one plate drilled on both sides which has circles of holes as follows:

First side——24–25–28–30–34–37–38–39–41–42–43
Second side—46–47–49–51–53–54–57–58–59–62–66

This company furnishes as an "attachment," three plates drilled on both sides with holes as follows:

Plate	*A*	30–48–69–91– 99–117–129–147–171–177–189
	B	36–37–81–97–111–127–141–157–169–183–199
Plate	*C*	34–46–79–93–109–123–139–153–167–181–197
	D	32–44–77–89–107–121–137–151–163–179–193
Plate	*E*	26–42–73–87–103–119–133–149–161–175–191
	F	28–38–71–83–101–113–131–143–159–173–187

This company also builds a "wide-range" divider unit, divisions 2 to 400,000.

Move the sector *immediately* after indexing, then it will always be in position for the next indexing operation.

The number of spaces on the index circle indicating the fractional part of a turn should be included between the *beveled* edges of the sector arms.

Form the habit of turning the *index handle to the right*, to avoid confusion. Stop between the last two holes and gently rapping the handle allow the pin to snap into place. If the handle is turned too far, turn back far enough to *take up the lost motion* before allowing the pin to snap into place.

Sometimes after the work has been exactly adjusted, to a cut already made for example, the index pin will come between two holes in the plate, and merely moving the pin to enter either hole will move the work a trifle, perhaps enough to spoil the cut. A means of allowing the pin to enter the nearest hole, *without moving the work at all*, is provided in the Brown and Sharpe machine by adjusting the screws *A* (Fig. 235), and in the Cincinnati machine, the index-plate lock is loosened, and the plate moved until one of the holes comes to the pin.

The worm and wormwheel and the spindle are so arranged within the swivel block as to permit of indexing in any position within the angular range, and this feature of the head is used for cutting clutches, end teeth on cutters and many other jobs.

232. Indexing in Degrees.—There are 360 deg. in a circle, and one turn of the index handle will revolve a point on the circumference of the work $1/40$ of a circle or 9 deg. Consequently one ninth of a turn (2 spaces, 18 circle—3 spaces, 27 circle—6 spaces, 54 circle) equals 1 deg. Further, the work may be indexed $1/2$ deg. (1 hole, 18 circle) or $1/3$ deg. (1 hole, 27 circle) and, of course, 2, 3 deg., etc., provided a circle divisible by 9 is used. For smaller divisions than $1/3$ deg. on the Brown and Sharpe machine, differential indexing is used, and for smaller divisions than $1/6$ deg. on the Cincinnati one of the three extra plates may be used. In either case it may be well to figure the number of divisions required; for example,

to index for $\frac{1}{4}$ deg. use four times 360 divisions or 1,440 divisions ($\frac{40}{1440} = \frac{1}{36}$ of a turn).

233. Direct Indexing.—The construction of the universal index head permits of disengaging the worm from the wormwheel. The object of throwing the worm out of mesh with the wormwheel is to make possible a very much quicker method of indexing, called direct indexing, for the more commonly used divisions. Disengaging the worm from the wormwheel is accomplished by turning through part of a revolution a knob

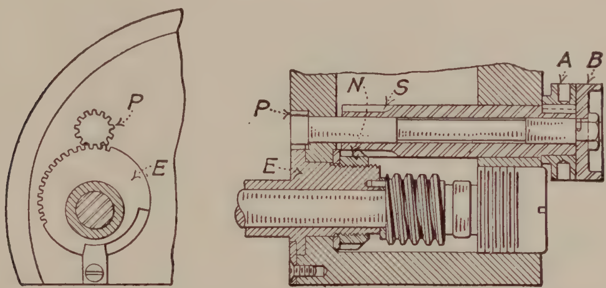


FIG. 236.—Portion of *horizontal* section Brown & Sharpe index head. To lower the worm out of mesh with the wormwheel, *first disengage stop pin from index plate*, then turn knob A about one-quarter revolution in the *reverse* direction to that indicated by an arrow on A. This will loosen nut N which clamps eccentric bushing E. (NOTE: The sleeve S and the nut N are provided with gear teeth.) After N is loosened, turn both knobs A and B; this will turn the pinion P and revolve the eccentric bushing E which lowers the worm.

or handle that operates an eccentric (see Figs. 236 and 237). In many designs of index heads, for example, in the Brown and Sharpe, the *stop pin* must be out of the index plate *before the worm is lowered.*

Direct indexing (sometimes called quick indexing) is accomplished, after the worm is lowered, by means of a plate with at least 24 equally spaced holes, which is fastened to the front of the work spindle, and a plunger pin which is located in the head and fits the holes in the plate (see Figs. 232 and 233). The plunger pin holds the plate in position. When the plate is turned by hand the required part of a revolution, the index spindle and the work also turn that same part of a

revolution. Direct indexing is used to advantage when milling squares or hexagons, fluting taps, counterbores, etc. Any number of divisions which is a factor of 24 may be quickly indexed; as, 2, 3, 4, 6, 8, 12, 24.

234. Differential Indexing.—The term *differential* is used because the needed division is obtained by a combination of two movements, (1) the simple indexing movement of the index crank, and (2) a movement of the index plate itself. The amount the plate moves for each turn of the index handle,

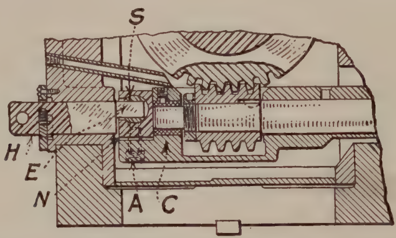


FIG. 237.—Portion of *vertical* section of Cincinnati index head. The worm is lowered out of mesh with the wormwheel by moving the handle H one-half turn. This operates eccentric E which is journaled crosswise in the cylindrical sliding piece S carried in the holder N. The worm carrier C is fastened to N (by two screws A) consequently when the slide holder N is raised or lowered the worm casing and worm are raised or lowered.

and the direction it moves, are governed by change gears as will be explained presently.

Differential indexing may be used for divisions that cannot be obtained by simple indexing, like 319 for example, which would need a plate with a circle of 319 holes. A little easier example is 41 divisions. Ordinarily this is merely a simple indexing operation using the 41 circle and taking $^{40}/_{41}$ turn each division. But if for any reason the 41 plate is not available, any index plate may be geared to move exactly $^{1}/_{41}$ of a turn toward the index crank while the crank is being moved the needed $^{40}/_{41}$ of a turn. In this case the division is correct when the index pin enters the hole from which it started. In other words, the hole in the plate has moved back $^{1}/_{41}$ of a turn, and the index pin has moved forward $^{40}/_{41}$ of a turn, and the indexing movement is exactly the same as if it had been $^{40}/_{41}$ on the 41 plate.

This appears rather confusing at first, but it is really not difficult. The gears to use and their arrangement offer about the same problems as gearing a lathe for cutting threads. Perhaps the first thing to understand is how the index plate is caused to move.

In simple indexing, the index plate is held from turning by a stop pin; the index crank is turned and serves to revolve the *wormshaft* in the *sleeve L* (Fig. 238), and the *worm* moves

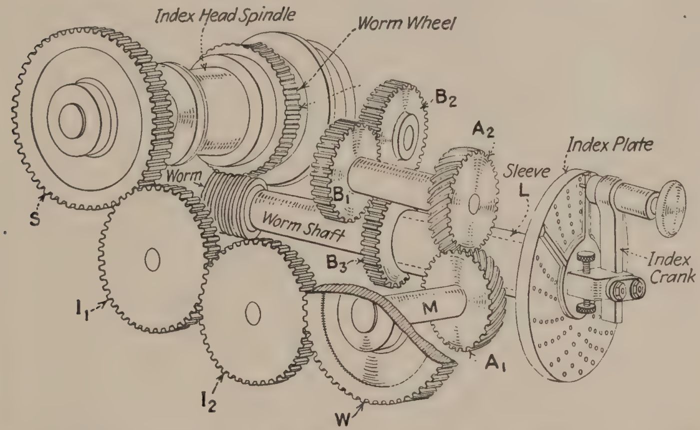


FIG. 238.—Illustrates the gearing for differential indexing with Brown & Sharpe index head (extended for clearness). In practice one idler, or two idlers, or a compound of any two of the change gears with or without an idler, may be used between the gears S and W.

the *wormwheel* and the *index-head spindle.* In differential indexing the stop pin is withdrawn.

Note, in the figure, that the gear B_3 and the index plate are both fastened to the sleeve L, and therefore if the gear B_3 is caused to move, the plate will move. In order to make the gear B_3 and the index plate move when the spindle moves, as in differential indexing, certain gears are arranged, the stop pin is withdrawn, and motion is transmitted from the spindle to the gear B_3. The permanent gears within the index head, as well as the change gears, are diagrammed in Fig. 238 to show how this motion is transmitted. The explanation follows:

A special arbor is fitted and held securely in the taper hole in the index-head spindle and is hereafter referred to as the "spindle." One end serves as the live center and the other end projects through and holds the spindle gear S.

Arrange the train of gears: the spindle gear S, the idler gears I_1 and I_2, and the worm gear W (on the auxiliary wormshaft M). Disengage the stop pin that locks the index plate to the head, turn the index crank and note the following: (1) The spindle, and the gear S, are put in motion by the movement of the index crank, through the wormshaft, worm, and wormwheel, in the ratio of 40:1, as in simple indexing. (2) The movement of the spindle gear S is transmitted through I_1 and I_2 to gear W. (3) From W, through shaft M, the motion is given to spiral gear A_1, to other spiral gear A_2, to B_1, which is fastened to the same stud as A_2. The gear B_2 is an idler gear, and motion is transmitted from B_1 through B_2 to B_3, the sleeve L and the *index plate.* (4) The amount the index *plate* will move, relative to the movement of the index *handle,* will depend upon the relative sizes of the driving and driven gears (as S and W, in simple train or compounded). (5) The movement of the index plate may be in the direction of the movement of the index crank, or in the opposite direction, according to whether one or two idlers are used.

Suppose there are equal gears, S and W, on the "spindle" and the "worm," respectively, with two idlers between them, and that the index pin is in a hole in the index plate referred to here as (1). Now pull out the index pin and move the index handle clockwise, then the index plate will move counterclockwise, and 40 turns of the index handle will cause the *index plate* to make one revolution, and the index pin will have caught up with the (1) hole just 41 times. If the handle is stopped each turn, that is, each time the pin comes to the (1) hole, and a cut is made, in a gear blank for example, a gear of 41 teeth will be cut.

Now if only one idler is used, the movement of the index plate is clockwise, or in the same direction as the movement of the index handle. By making 40 turns of the index handle, the pin catches up with the (1) hole just 39 times, because of the

one whole turn of the plate itself. If a cut is made each time the pin reaches the (1) hole, 39 cuts will be made.

Investigate a little further by putting a 48-tooth gear on the spindle, a 24-tooth gear on the worm, and use one intermediate. The ratio of the spindle to worm is then 2:1, and when the spindle revolves once, the index plate will revolve twice, and the index pin will have caught up with the (1) hole 38 times.

With the above setting (with one idler), a "turn" from (1) hole to (1) hole each indexing will give 38 divisions; with 2 turns, 19 divisions; with $\frac{1}{2}$ turn, 76 divisions; $\frac{2}{3}$ turn, 57 divisions, etc. With two idlers, divisions as follows may be made: 1 turn, 42; 2 turns, 21; $\frac{1}{2}$ turn, 84; $\frac{2}{3}$ turn, 63 divisions, etc.

With a ratio, spindle to worm, of 3:1, the machinist can make, with one idler, 1 turn, 37 divisions; $\frac{1}{2}$ turn, 74 divisions, etc. With two idlers, 1 turn, 43 divisions, etc.

Take a fractional ratio of spindle to worm, for example, $\frac{2}{3}$:1 (that is, 2:3), 32 gear on spindle, 48 gear on worm:

$$40 - \tfrac{2}{3} = 39\tfrac{1}{3}$$

One-third turn ($39\frac{1}{3} \div \frac{1}{3}$) gives 118 divisions.
Two-thirds turn ($39\frac{1}{3} \div \frac{2}{3}$) gives 59 divisions, etc.

Enough has been said to illustrate the principle of differential indexing, how different ratios of gears from spindle to worm give divisions, such as prime numbers, that would otherwise be impracticable if not impossible. Following is an explanation of how the gear ratios are calculated, and, to simplify the calculations, definitions and notations are given:

Definitions, Notations, Etc.

Simple index number (40)—the number of turns of the index handle to turn the spindle one revolution as in simple indexing.

Differential index number (D)—the number of moves (turns) of the index handle [from (1) hole around to (1) hole] necessary to make one complete revolution of the spindle.

Change-gear ratio (x)—the ratio of the train of gearing between the spindle and the worm (and, *in effect*, between the spindle and the index plate).

NOTE.—It will be observed from the examples given that the change-gear ratio is always the ratio of the difference between the simple index number and the differential index number and 1. For instance, in one of the examples given above the difference between 40 and $39\frac{1}{3}$ is $\frac{2}{3}$, or a *ratio* of spindle to worm of $\frac{2}{3}:1$ or $2:3$.

(1) 40 = simple index number.

(2) D = differential index number.

(3) N = number of divisions required.

(4) N_1 = some number of divisions, usually quite near the required number, that may be obtained by simple indexing.

(5) S = gear on spindle, (6) G_1 = first gear on stud: $\}$ driving gears.

(7) G_2 = second gear on stud, (8) W = gear on worm: $\}$ driven gears.

(9) $D:40 = N:N_1$ that is, $D = \dfrac{40N}{N_1}$

(10) x = ratio = $(40 - D):1$, when 40 is larger than D.

(11) x = ratio = $(D - 40):1$, when D is larger than 40.

(12) $x = \dfrac{S}{W}$ (for simple gearing).

(13) $x = \dfrac{S \times G_1}{G_2 \times W}$ (for compound gearing).

(14) The ratio should not exceed $6:1$ on account of the excessive stress on the gears.

(15) When the differential index number is less than 40, use one idler (or the compound); when greater than 40, use two idlers (or one idler and the compound).

(16) The movement of the index handle will be the fraction of a turn indicated by $\dfrac{40}{N_1}$.

NOTE.—The numbers in parentheses in the following explanation and examples are references to the notations above.

Method of calculations:

a. Select N_1. . . . . (4)
b. Substitute for N_1 its value, and solve for D. . . . . (9)
c. Find the ratio. . . . . (10) or (11)
d. If the ratio is not practicable (14), select another number for N_1 and try again
e. Having ratio, arrange simple gears. . . . . (12)
or compound gears. . . . . (13)
f. Set the index pin and sector. . . . . (16)

In the illustrations showing two setups for differential indexing, Fig. 239 shows the *quadrant* type of index head and Fig. 240 shows the *trunnion* type. Either kind may be used.

Example 1.—$N = 59$. (3)

Solution.—$\frac{D}{40} = \frac{N}{N_1} \qquad \frac{D}{40} = \frac{59}{60}$ (9)

$$60D = 40 \times 59$$

$$D = \frac{40 \times 59}{60}$$

$$D = 39\tfrac{1}{3} \tag{9}$$

$$x = (40 - 39\tfrac{1}{3}):1 = \tfrac{2}{3}:1, \quad \text{or} \quad 2:3 \tag{10}$$

$$\tfrac{2}{3} = \tfrac{48}{72}; \quad 48 \text{ gear on } S, \quad 72 \text{ gear on } W \tag{12}$$

Use one idler, I (15)

Movement of index handle $\frac{40}{60} = \frac{2}{3}$ turn (16)

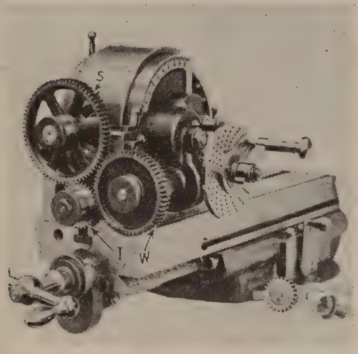


FIG. 239.—Brown & Sharpe index head geared for 271 divisions.

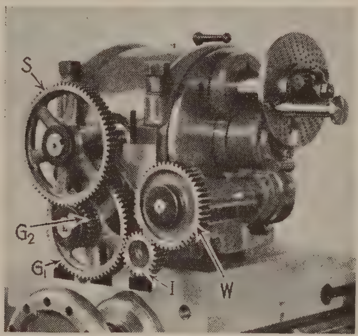


FIG. 240.—Brown & Sharpe index head geared for 319 divisions.

Example 2.—(Fig. 240) $N = 319$. (3)

Solution.—Assuming N_1 as 320 for a trial, it is found to give a ratio of 8:1 which exceeds 6:1 and is not practicable (14). Trying 340, and then 300, both are found to give awkward ratios. Selecting 290 for N_1 gives a ratio of 4:1, thus:

$$\frac{D}{40} = \frac{319}{290} \tag{9}$$

$$290D = 40 \times 319$$

$$D = \frac{40 \times 319}{290} \tag{9}$$

$$D = 44$$

$$x = (44 - 40):1, \quad \text{or} \quad 4:1 \text{ ratio} \tag{11}$$

With as large a ratio as 4:1 it is better to compound, thus

$$\frac{4}{1} = \frac{12}{3} = \frac{3 \times 4}{1 \times 3} = \frac{72 \times 64}{24 \times 48}$$

72 gear on S; 64 on G_1; 24 on G_2; 48 on W (5), (6), (7), (8), (13)

Use one idler (15)

Movement of index handle = $^{40}\!/_{290}$ = $^{4}\!/_{29}$ turn (16)

The card furnished with the machine gives the gears for divisions in general use, and the Brown and Sharpe treatise gives the gears for divisions to 1,008.

235. Wide-range Divider.—The Cincinnati Milling Machine Co. have a *wide-range-divider* unit that may be built into their dividing head. It may be used for divisions from 2 to 400,000 and for any desired angle in degrees, minutes, and seconds (see also footnote on page 275 for three special plates).

Questions on the Index Head and Indexing

1. The work spindle is turned by an enclosed worm and wormwheel. In certain other machines, possibly on the drill press, the action of the worm and wormwheel may be seen. Find an example.

2. How can you determine the number of teeth on the wormwheel in the dividing head?

3. How many turns are necessary to index for a gear of 20 teeth? For 40 teeth? For 80 teeth?

4. State a rule for determining the number of turns or the fractional part of a turn of the index handle to be made for any given number of divisions.

5. How many circles of holes has the index plate that is on the head? How many of these circles are divisible by three? How would you obtain two thirds of a turn?

6. Are there any index plates other than the one on the head furnished with this machine?

7. How may the index crank be adjusted radially to permit the pin to enter a hole in the desired circle?

8. What do you use to save counting the holes for every move? How are the arms adjusted and set to include the desired number of holes?

9. If two thirds of a turn is required and an 18-hole circle is used, what number of *holes* is included between the arms of the sector? Why not 12?

10. What part of a turn will you make to cut a gear of 42 teeth? What circle will you use? How many holes will be included between the arms of the sector?

11. In which direction should the index crank be turned? Why?

12. What keeps the index plate from turning when the crank is turned?

13. Tip the head to a vertical position. Can indexing be accomplished? Tip the head to 45 deg. Are you able to index in this position?

14. In some makes of index heads a plate with 24 divisions is fastened to the spindle just back of the driver. What is the use of this plate?

15. How may the worm be disengaged from the wormwheel? When is this necessary? Why?

16. Before disengaging the worm why is it necessary to take out the stop pin? Why is it unnecessary to take out the index pin?

17. What advantage has direct indexing? Why are there 24 holes in the direct index plate? How are these holes numbered?

18. Rearrange the dividing head for simple indexing. How do you know when the worm properly engages the wormwheel?

19. Obtain a rod (brass is best) about ¾ in. in diameter, 6 or 7 in. long, and knock out the index-head center. When is the center removed from the dividing-head spindle?

20. What standard taper has the spindle hole?

21. Why is a guard screwed on the nose of the spindle when the center is being used?

22. How is a chuck mounted on the index-head spindle?

23. What block is needed in order to set the dividing head at any other angle than parallel with the table? How do you set this block square? How do you set it at any other angle?

24. How do the tailstock of a lathe and the footstock of a milling machine compare in purpose?

25. What adjustment does the tailstock have that the footstock does not have?

26. Frequently one or more square- or hexagonal-head taper pins are used to locate and "anchor" a movable part in its normal position. Are you able to find such a feature in the footstock?

27. Do your calculations for 271 divisions give the same gears as shown in Fig. 239 (72 on S, 56 on W, one idler)?

TYPICAL INDEXING OPERATIONS

236. Milling a Square or a Hexagon.—The size of a square or a hexagon is always given as the distance "across flats," not "across corners." It will be understood that the distance across corners, if known, will give the diameter of the cylinder on which the given square or hexagon may be cut.

It may be desirable to know the largest square or hexagon that may be cut on a given cylinder, and it frequently happens that the machinist must first turn in a lathe the cylinder on which he is to cut a square or a hexagon of a given size across flats. In this connection the table on page 479 will be found useful.

The diameter multiplied by 0.707 will give a square with sharp corners. Multiplying by 0.750 will, of course, give a square a trifle larger and leave a small part of the original circle on each corner. The toolmaker, milling the squares on taps, reamers etc., mills the distance across flats three fourths of the diameter of the shank, to leave the corners slightly rounded.

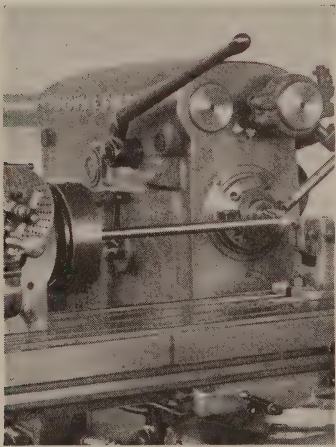


Fig. 241.—Milling a square end on a long piece. Index-head spindle is horizontal.

When milling the square or hexagon on a bolt or similar piece, it may be necessary if the work is long to hold the piece between centers, or perhaps in a chuck and supported by the footstock center, and take a vertical cut (Fig. 241). It is advisable, however, when practicable, to knock out the index-head center, using a suitable brass rod and a hammer, tip the head spindle to a vertical position, take off the nose guard which protects the thread on the nose of the spindle, screw the chuck on the spindle and hold the work vertically in the chuck.[1] A protecting piece of brass or copper may be needed between the chuck jaws and the work. A piece held vertically is shown in Fig. 242.

To keep the chips that may fall in the hole from becoming lodged between the swiveling block and the base plate and

[1] A piece of brass rod about ¾ in. in diameter, 6 or 8 in. long, is very useful for knocking out the center, and a babbitt hammer for driving home the collet or the end mill, or the arbor if no draw-in bolt is provided. Read number 4, page 258.

possibly (later when the swiveling block is moved) scoring one or the other, a cap is provided that fits in the small end of the spindle hole. If the cap is not at hand, stuff a small quantity of waste in the hole. Be sure the chuck is screwed *tight* against the spindle shoulder.

Using an End Mill.—By holding the work vertically the regular table feed may be used and the cutting action more easily observed. Further, if a number of pieces are to be milled, straddle mills may be used. If only one cutter is used, a suitable end mill is selected, and the *direction of the cutter and the feed should be so arranged as to tend to screw the chuck on rather than to unscrew it.*

Read again the directions 1, 2, and 3, page 257. Assume a cylindrically turned head of a tool-post screw, for example, is to be milled square using an end mill. The amount of stock to be removed from each side will equal one half the difference between the diameter of the turned head and the distance across the flats when finish-milled. This amount will probably be removed in one cut, but when milling the first piece it is best to take two opposite roughing cuts, measure across, subtract from this measurement the finished dimension, and move the work in one half the difference.

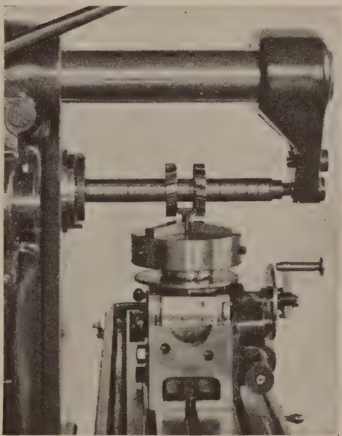


FIG. 242.—Straddle milling a square on a short piece. Index-head spindle is vertical.

Using Straddle Mills.—When any considerable number of pieces are to be milled it will be advisable to straddle-mill them. Obtain a pair of side-milling cutters of the same diameter, of such a size that the collar between them when arranged on the arbor will clear the top of the work. Clean the hole in the spindle, also the shank of the arbor, and *be sure the arbor is firmly held.* Leave enough collars on the arbor to bring

the first cutter in about its proper position with reference to the work when the worktable is fairly close to the column. Select a collar (possibly two or more) that will fill the space between the *hubs* of the cutters when the *cutting edges* are the right distance apart. It may be necessary to use two or three "spacers" made of paper or some thin metal.

Put on the other collars and the nut, having the bearing collar so placed on the arbor as to bring the outer arbor support as close to the cutters as the work (and chuck) will permit.

It is now necessary, first, to make sure that the cutters are correctly spaced and, second, that the work is correctly positioned laterally. It will be best, in order not to injure or possibly spoil one of the pieces to be milled, to get a piece of scrap of approximately the size of the work and catch it in the chuck. Feed the table by hand laterally until the work appears central, and vertically until a cut ⅛ in. or more deep may be made across the top of the scrap piece. Start the machine and feed into the piece far enough to be able to get a measurement across the flats and by so doing find if more or less space is advisable between the cutters. Add or take away spacers as needed to give the accuracy required and take another cut to check the result. It may be necessary for the beginner to make three or four changes before he gets the right thickness.

After making the cut of the right thickness across the piece run the work back and index halfway around. If the work will now pass between the cutters without either cutter taking a chip it is central. If it is not central one cutter will remove metal and reduce the thickness of the head a certain amount, the other cutter will be a like distance away from the surface. To correct the setting, measure the thickness as now cut and subtract it from the thickness previously cut and feed the work one half this difference away from the cutter that took the chip. It will be advisable to check this setting to insure accuracy, after which the work to be milled may be placed in the chuck and the table adjusted vertically

until the correct depth of cut is obtained. Make sure that each succeeding piece projects from the chuck the same distance in order to maintain uniformity; possibly a freely fitting collar under the head of the bolt or screw being milled will be an advantage.

Questions on Milling a Square or a Hexagon

1. What care must be taken when putting the chuck on any machine spindle?

2. How is the index-head center removed?

3. For what purpose is the cap in the end of the hole?

4. How are the swiveling-block bearings oiled? How often?

5. If only a few bolts are to be squared, why is an end mill the best cutter to use?

6. When setting up, rough one side of the bolthead then the opposite side, measure across and move the work toward the cutter one half the amount of the oversize. Why is this the correct method of procedure? Is this correct when the work is held horizontally instead of vertically?

7. Would the vertical feed or longitudinal feed be used to mill the square on the end of a reamer held between centers? Why? What feed is used when the work is held vertically? Give reason?

8. If a considerable number of bolts are to be squared why is straddle milling the better method?

9. Lay the edge of a scale across the face of the side mill, and look under it. Have the side teeth any other clearance than the land clearance? Give reason.

10. Is the length of the hub equal to the width of the face of the cutter?

11. If it is desired to use a pair of these side mills for straddle milling will a collar the same thickness as the width of the cut be used? What thickness will be used?

12. Why are the collars for milling arbors furnished in various thicknesses or lengths?

13. Why are spacers of thin metal valuable when using straddle mills? Could paper be used?

14. Do the side teeth of a side mill cut when straddle milling? Of what use are they?

15. Why is it advisable to slightly round the corners of side mills with an oilstone?

16. What would be the value of a small collar under the head of the screw or bolt being milled?

17. How many turns of the index handle are necessary to mill a hexagon bolthead? What circle do you use? How many holes? How many holes are included between the arms of the sector?

18. How would you proceed to obtain the correct size across the flats when using a pair of straddle mills?

19. How would you proceed to make sure the head is central?

20. Could the outside face of the outside straddle mill be used as suggested in question 6 to obtain a head of the right size and central?

237. To Cut a Spur Gear. 24 Teeth, 10 Pitch.—For typical setup see Fig. 170. For gear information see Chapter XVIII.

1. Obtain from the toolroom or elsewhere a 10-pitch gear cutter No. 5, a mandrel to fit the gear blank, a suitable arbor for cutter, a dog, etc.

2. Oil the mandrel, press it in the gear blank *tight* and put the dog on end furthest from gear.

Fig. 243.

3. Be sure the index centers are in line (horizontally).

4. For indexing 24 teeth,

$$40 \div 24 = 1\tfrac{16}{24} = 1\tfrac{2}{3}$$

turns of index handle. Arrange the index pin in any circle divisible by 3 and set the sector to include two thirds of the number of spaces. Be sure the index handle turns freely and that the sector moves easily enough.

5. Run the table in practically to the column for sake of rigidity.

6. Arrange the cutter arbor in the spindle and arrange the cutter on the arbor in a position substantially over the center line of the index centers.

7. Raise the table if necessary and run the dead center nearly to the cutter and adjust until it appears central as in Fig. 243. This is probably near enough.[1]

[1] To set a cutter exactly central, for example, a gear cutter or similar cutter, it is best to use a trial blank. This trial blank may be of any convenient size and should be mounted in the usual way as near central with the cutter as possible. Take one cut through the blank, then removing the dog turn the work end for end and replace between centers without the dog. Apply blue vitriol to sides of the groove already cut and feed the cutter into the groove $\frac{1}{16}$ or $\frac{1}{8}$ in. One or two revolutions of the cutter is all that is necessary. If it is out of central, the appearance of the surface of the groove will indicate clearly that the cutter is remov-

8. Lower the table and arrange the work between centers, *lightly* clamping the tail of the dog in the carrier slot. Do not tighten the clamping screw too much or the dog and, consequently the work, will be cramped.

9. Before starting the first cut be very sure there is no chance of the arbor yoke hitting the tail of the dog or the dog screw during *any* cut.

10. Run the work under the cutter and raise the worktable until paper is torn between the revolving cutter and the blank, then 0.001 in. or 0.002 in. more until the cutter just touches the work.

11. Set the graduated collar on the vertical feed at zero.

12. Run the work from under the cutter and raise the table to position for the roughing (stocking) cut. Full depth of tooth space (10-pitch gear) is 0.216 in.; roughing cut about 0.180 to 0.190 in.

13. Rough one tooth—and set the automatic feed trip.

14. Run the table back to starting position. *Always be sure to run it back far enough.*

15. Index $1\frac{2}{3}$ turns for the next tooth, and so on until all teeth are roughed.

16. Raise the table to 0.216 in. (full depth of cut) and take the finishing cut for each tooth. When finishing, stop the cutter before running back (see paragraph 203, page 244).

Questions on Cutting a Spur Gear

1. If the gear blank is to be mounted on a mandrel for milling the teeth, why do you put oil on the mandrel before forcing it in the hole?

2. Why must the index centers be in line?

3. How will you arrange the sector? Why?

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ing stock from the top of one side and from the bottom of the other side.

In case the cutter is not central, the work should be moved laterally in the direction away from the side of the groove from which the stock was removed on the top, and another groove cut and the above operation repeated until the cut is central.

If the cutter is exactly central, the outline of the second cut will coincide with the first and a slight but even amount of the blue vitriol will be removed from the surface of the groove under the cutter.

4. In which direction do you turn the index handle? Why?

5. How do you select the proper cutter? What do the letters and figures stamped in the cutter indicate?

6. How is the cutter set approximately central by means of the dead center? By means of a square against the dead center?

7. How is the cutter set approximately central by cutting a very small spot on top of the blank and locating the cutter to line with the spot?

8. How do you determine whether the cutter is central by cutting a groove, say two thirds of the depth of the tooth, than reversing the work end for end, painting the groove with blue vitriol and noting where the cutter touches the sides of the groove when recut with the same setting?

9. Why do you leave the dog off when recutting the groove as in Question 8?

10. Why are screws provided to clamp the tail of the dog? How tight should the tail be clamped? Give reason.

11. How do you calculate the number of revolutions of the spindle to give the proper cutting speed for this job?

12. How do you determine the proper roughing feed? Finishing feed?

13. How much stock do you leave for a finishing chip?

14. How do you determine the depth of the cut to be made to give the correct gear tooth?

15. Is it good practice for the beginner to nick the teeth all around before cutting the gear? Give reason.

16. What is meant by a formed cutter? Is the gear cutter you are using a formed cutter?

17. How should the formed cutter be ground to preserve the original shape of the cutting edge? Why?

18. What is a fly cutter? When is it advantageous to make and use a fly cutter? How is a fly cutter held?

19. If, for example, a new gear was needed on a repair job and no cutter of the proper pitch was immediately available could a fly cutter be made quickly that would answer to cut the gear?

238. Fluting Reamers, Taps, Etc.—Standard cutting tools like drills, milling cutters, reamers, taps, counterbores, etc., can be purchased in the open market much cheaper than they can be made in the average shop because the manufacturers of these tools have special facilities for quantity and quality production. Since *special* tools are expensive anyway and very often the delay incident to having them made outside makes this course prohibitive, it may be economical and often necessary to make them, especially reamers, taps, and cutters.

This means that the resourceful machinist is able to turn, mill, harden, temper, and grind these tools.

Reamers and taps are cut with special cutters (Fig. 201). The operations incident to setting up the machine and taking the cut are substantially alike. The number of teeth and the width of the land depend upon the size and purpose of the given tool. If a drawing is not furnished possibly a standard tap or reamer of about the size called for is available for use as a model. Tables of sizes of all such tools are given in American Machinists' Handbook.

A double-angle cutter is best for fluting reamers, taps, end mills, etc., for the reason that both sides of the groove are then clean cut, that is, no part of the surface of the groove is scored by the dragging of chips. (This scoring often happens when a straight-faced single-angle mill is used, also when using an end mill or a side mill for a facing cut.)

Most reamers are cut with the face of the teeth *radial*. To cut the groove with one side radial when using a double-angle cutter, it is, of course, necessary to offset the work laterally. The amount of offset depends on the number of teeth, the width of the land and shape of the cutter. Cutters vary in shape, and in many cases the "cut-and-try" method is preferred. If the cutter has a 30-deg. side, as in Fig. 244, the end layout may be used to advantage, especially by the beginner. In either case judgment and care are necessary. *Study both methods*, they have many common features.

The beginner will find it rather difficult to set the cutter so that when the face of the tooth is *radial*, the *land* is of the required width, and it will be advisable, for the first job at least, to use a practice piece of the same size as the reamer or tap.

239. The Cut-and-try Method.—Apply blue-vitriol solution on the end of the blank and, using a center square and a sharp scriber, draw a radial line. Tighten a dog on the work, place on centers, and turn the index handle to line up the shorter edge of the cutter with the radial line as shown in *a*, Fig. 244, for a trial cut. It is better to have the trial cut *somewhat*

less than the proper depth for the reason that it may be necessary to index the work a trifle more, or to move the table laterally a trifle, or possibly both. Cut a short distance in the first groove, run back, index to the next groove, and cut a short distance in that. Note if the cutter splits the line, and note also the width of the land. Assume the line is split,

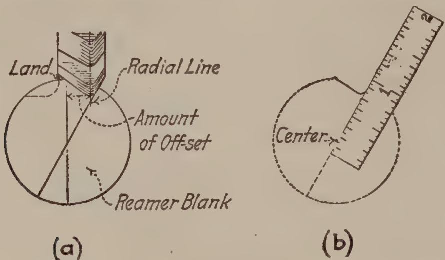

FIG. 244.—(*a*) Setting reamer cutter. A radius is a straight line drawn from the center to the circumference. A radial tooth face will split the radial line. (*b*) Checking radial face of tooth.

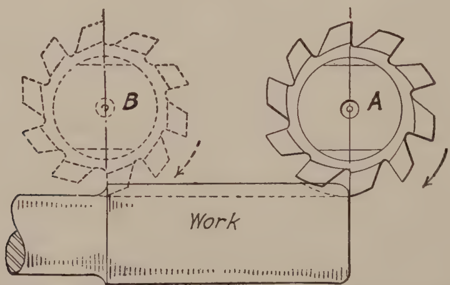

FIG. 245.—*A*, cutting full depth of groove; *B*, end of cut. The feed trip should be set to operate when the axis of the cutter is directly over the shoulder.

giving a radial face to the tooth, but that the land is *too wide.* In this case it will be necessary to feed the table laterally moving the radial line away from the cutter so that when the table is raised for the deeper cut, the radial face of the tooth will be merely touched, not cut into. If the trial-cut tooth face is not parallel to or splitting the radial line, it will be necessary to "roll" (index) the work a little one way or the other.

To check the setup, stop the machine, remove the blank, and placing a scale against the tooth face, see if it is radial as in *b*, Fig. 244.

When the setting is correct, substitute the reamer for the trial piece. Remember that the cutter does not cut its full depth until the axis is over the end of the piece *A* (Fig. 245). Remember also to set the feed trip to operate when the axis is over the shoulder of the tap or reamer as shown at *B*. Read paragraph 219, page 260, and set the stop.

240. The Layout Method.—It may be easier, with cutters having a 30-deg. angle, to scribe two radial lines and index the

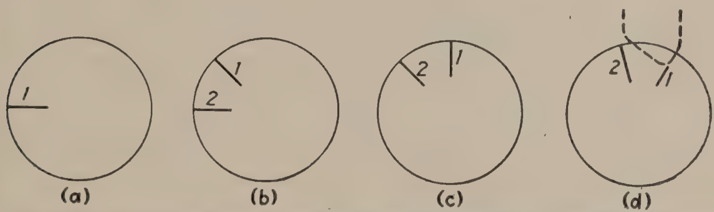

FIG. 246.—Scribing lines for an eight-tooth reamer: (*a*) with the scriber of the surface gauge set on center, scribe line No. 1; (*b*) index 5 turns for one tooth space, and scribe line 2; (*c*) index 5 turns to bring line 1 to a vertical position; (*d*) index 3⅓ turns (30 deg.) to bring line 1 to position for face of tooth, 30 deg. past vertical.

first line until it is 30 deg. beyond the vertical as shown in Fig. 246. In a study of the four steps given in Fig. 246 it will be observed (1) that the purpose of scribing the lines 45 deg. apart as in *b* is that there are eight teeth in the reamer and the faces of the teeth are 45 deg. apart; (2) that *c* shows the second indexing step to get No. 1 line in a vertical position; (3) that indexing this line 30 deg. from the vertical, as in *d*, brings it in the correct relation to the 30-deg. side of the cutter; and (4) that the No. 2 line serves in *d* as a guide line to show the width of the land.

If there were, for example, six teeth in the reamer, the first indexing would be 60 deg. (6⅔ turns), then 30 deg. (3⅓ turns), to get the No. 1 line vertical, then 30 deg. (3⅓ turns again), to get the No. 1 line in correct position for the 30-deg. side of the cutter.

241. Unequal Spacing or Increment Cut.[1]—When the teeth of a hand reamer are equally spaced, the tendency is for each tooth to cut a trifle deeper than the preceding tooth, which produces a hole with a wavy surface—as many waves as there are teeth. Therefore, hand reamers are usually made with unequally spaced teeth.

The general rules to be observed for cutting reamers with unequally spaced teeth are:

Number of flutes must be even.

Faces of teeth must be opposite.

If L is the largest space between two teeth and S the smallest, and the smallest space follows the largest; then the difference between L and S should not be over 6 deg.

The number of teeth on Brown and Sharpe solid hand reamers are as follows:

$\frac{1}{8}$ in. to $1\frac{7}{32}$ in.—(6); $\frac{9}{16}$ in. to $1\frac{3}{32}$ in.—(8); $1\frac{1}{8}$ in. to $1\frac{15}{32}$ in.—(10); $1\frac{1}{2}$ in. to $2\frac{1}{16}$ in.—(12); $2\frac{1}{8}$ in. to $2\frac{9}{16}$ in.—(14); $2\frac{5}{8}$ in. to 3 in.—(16).

As an illustration of the operation let it be required to cut a 1-in. reamer with eight teeth (Fig. 247). Assume the cutter is set to give a radial tooth of approximately the proper depth or a little less and that a 39 index circle is being used.

It will be advisable to start each successive reamer from the original position of the index handle, for example, cut the first flute in each reamer when the index pin is in the numbered hole in the circle. (Note in Fig. 247 that "8th index" will bring work to original position.)

Proceed as follows:

1. Cut the first flute.
2. Index 5 turns (1st index regular) and cut second flute.
3. Index 5 turns plus 15 holes (2d index) and cut (3).
4. Index (from the hole the pin is now in) 5 turns minus 10 holes (3d index) and cut (4).
5. Index (from the hole the pin is now in) 5 turns minus 5 holes (4th index) and cut (5).

[1] For indexing movements for fluting reamers with unequal spacing see Table 10, page 487.

The fifth flute is now cut and the cutting face of (5) is exactly opposite the face of tooth (1).

The indexings for the teeth (6), (7), and (8) are duplicates of the movements 2d, 3d, and 4th, respectively, and the 8th index which is a duplicate of the 5th will bring the index handle to the original position.

Since opposite teeth are exactly opposite, many machinists prefer to cut a given tooth and then its opposite. Thus in Fig. 247, cut 1, then index 20 turns and cut 5; index for (6), cut

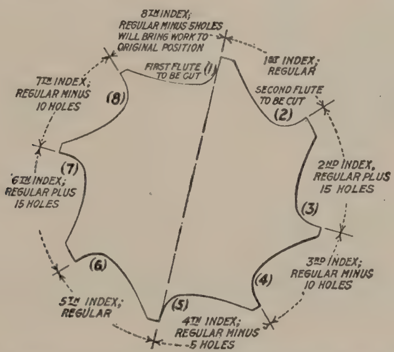

FIG. 247.—Shows moves for unequal spacing of reamer having eight teeth.

6, and index 20 turns and cut 2; index for (3) and cut 3 then 20 turns and cut 7, etc.

If the wider lands are too wide, lower the work a trifle and rotate the work to trim off the tooth, next trim opposite tooth; then arrange to trim back of another tooth and its opposite, etc.

242. Fluting Taper Reamers.—It is obvious that to mill taper work, the center line of the work must be out of parallel with the cutting line. The best method of milling tapers is to arrange the index centers on the tilting table (Fig. 172), which is readily adjusted to bring the "cutting line" the necessary amount out of parallel with the center line of the work without disturbing the alignment of the index centers.

The tilting table is a very special fixture not often available, and the usual method of milling tapers is either to elevate

the tailstock center or lower the index-head spindle a sufficient amount to bring the cutting line horizontal.

When setting up to flute a taper reamer the cut-and-try method is probably the quickest and best, provided care and judgment are exercised. The lands on a taper reamer are usually a trifle wider at the large end than at the small end,

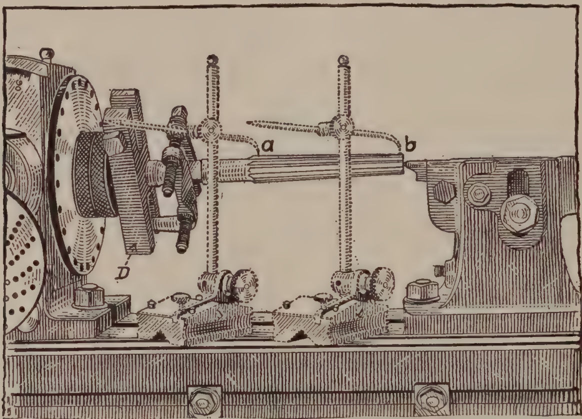

FIG. 248.—Setup for milling flutes in taper reamer. A reamer already milled may be used to show that although the index-head center is depressed to bring the bottom of the groove horizontal, that is, in the "line of cut," the cutting edge at *a* will still be higher than at *b*.

First adjust the head center until the bottom of the groove is horizontal as indicated by the surface gage, then adjust the scriber to touch the edge of the tooth at *a* and moving the surface gage to position *b* note the space at *b*.

Further, index for half the teeth and note that for each tooth the tail of the dog is in a slightly different position in the slot in the driver *D*. This shows that the work will be cramped unless the tail-binding screw is loosened before each indexing.

but even so the flute is wider and deeper at the large end. Consequently the top of the reamer when set up is not horizontal but a trifle higher at the large end.

Assuming the work to be adjusted vertically and laterally to give a radial tooth on the small end (as explained in paragraph 238), the preliminary adjustment for inclination of work will appear as in Fig. 248, with the point *a* of the reamer a trifle higher than *b* to cut the tooth deeper toward the large end, how much deeper depending on the amount of taper, number

of teeth, etc. It is a good plan for the beginner to proceed as follows: After setting the reamer as nearly right as may be judged, cut a short distance in two adjacent teeth at the small end and get the land the desired width. Set the vertical graduation at zero. Lower the table and run the work under the cutter until it is in position at the end of the cut (exactly over the shoulder at the large end of reamer). Then by raising the table, take two adjacent cuts until the land between is of the right width for this end of the tooth. Note the graduation on vertical adjustment; if the same as on small end the setup is right. If incorrect, the readjustment of the

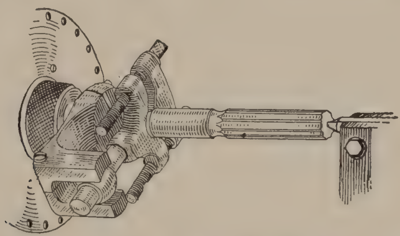

FIG. 249.—Milling-machine dog. The feature of this dog is the ball-and-socket drive which prevents any tendency to cramp the work. (*Courtesy of Ready Tool Company.*)

center up or down may be made until the bottom of the groove at each end feels the same with the surface gauge. If a sample reamer is at hand, it may be profitable for the beginner to set up the sample and then substitute the reamer he is to cut.

If a regular bent-tail dog or clamp dog is used, it will be necessary before indexing to loosen the screw which clamps the tail of the dog in the driver; otherwise the work is likely to become cramped and possibly sprung.

The milling-machine dog illustrated in Fig. 249 is very useful, especially in milling tapers. The construction eliminates the necessity of adjusting any clamping screw since all likelihood of shake in the driver or cramping or springing the work is avoided.

243. Drilling and Boring in a Milling Machine.—Drilling and boring may often be efficiently accomplished in a milling

machine especially in jig work, or work of like nature (Fig. 171). The spacing between the holes may be obtained by means of the graduations on the feed screws, or the holes in the smaller circular jigs may be spaced by indexing.

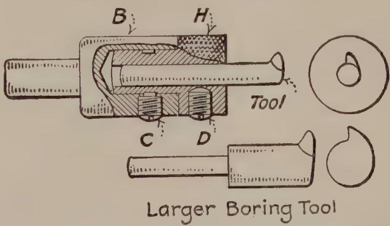

FIG. 250.—Eccentric boring-tool holder and tools.

Various adjustable boring-tool holders are manufactured. Figure 250 shows one type that may be easily and quickly made. It may be provided with a taper shank to fit a collet or with a straight shank and held in a chuck.

The holder *H* is provided with a stem which is turned eccentric 1/16 in. off center to fit the hole bored 1/16 in. off center in the body *B*. A hole of perhaps 1/4 or 5/16 in. in diameter is

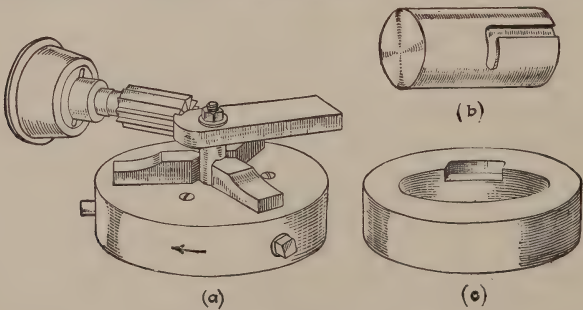

FIG. 251.—Shows work *fed* with index handle.

provided through the center of the holder and on through the stem to receive the shank of the boring tool which may be of any required length or size.

244. Feeding with the Index Handle.—The index-head worm and wormwheel movement is frequently used for *feeding* the work against the revolving cutter. Figure 251 shows three

types of jobs that are easily accomplished in this way: (*a*) illustrates how the end of the work may be milled to a given radius; (*b*) shows a cylinder in which a groove has been milled lengthwise by the regular feed and then a continuation of the groove at right angles milled by feeding with the index handle; (*c*) shows a piece having a recess cut to a given depth part way around the hole.

Questions on Fluting Taps and Reamers, Boring, Etc.

1. When may it be economical to make taps and reamers instead of buying them?

2. Why is an angular cutter inferior to a special double-angle cutter for fluting reamers?

3. Why is it necessary to offset the work from under the center of the cutter?

4. Why, do you suppose, is the cut-and-try method of setting the cutter advocated by machinsts?

5. When setting up, if the radial line of the layout is split, but the land is too wide, what correction is made?

6. What is the advantage of an increment-cut reamer? Why are the opposite teeth milled exactly opposite? Is this necessary in a taper reamer?

7. How may the index centers be adjusted to mill the flutes in a taper reamer?

8. Explain the disadvantage of using a bent-tail dog or a clamp dog when milling tapered work.

9. If you had a sample taper reamer to duplicate, how would you use a surface gage when adjusting the heights of the index centers? Would you set the surface gauge pointer to the bottom of the groove or on the land of the tooth? Why?

10. If you had no sample, how would you use the surface gauge?

11. Explain how one may do drilling, boring, and reaming in a milling machine.

12. What is the advantage of an adjustable boring-tool holder?

13. How may the indexing device be used for feeding the work?

14. Does the chuck screw on the spindle right-hand or left-hand?

15. What precautions would you suggest to avoid the tendency of the chuck to loosen under the pressure of the cut?

CHAPTER XIII

SPIRAL MILLING

245. Introduction.—There are certain operations in machine-shop work which seem to appeal to the student or apprentice as being particularly interesting and worth while. One of them is cutting a thread in a lathe and another is milling a spiral in the milling machine. Both *are* interesting and both *are* well worth while because each of them involves straight thinking and sound reasoning, and perhaps the intelligent accomplishment of either serves to develop the knowledge and skill of the student to a greater degree than any other single operation in either machine.

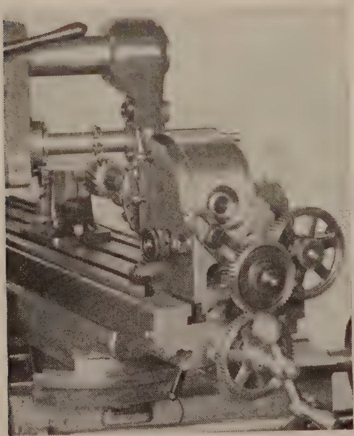

FIG. 252.—Milling a spiral cutter.

Spiral work includes the milling of spiral milling cutters, counterbores, twist drills, spiral gears, cams with spiral grooves, etc. In the manufacture of these articles special machines are used, but any of them of a special nature or that are required quickly in small lots may be profitably made in the universal milling machine.

There are points of similarity in cutting a thread and milling a spiral. In cutting a thread the tool moves a certain distance while the work revolves once and this distance is the *lead* of the thread and is governed by the "change gears" used. The same is true of milling a spiral, only it may be more proper to say that while the work is feeding against the

cutter, it is caused to revolve, and the distance it would have to feed in order to revolve once is the "lead" of the spiral. While the lead of a thread is usually short in proportion to the diameter and length of the thread, the lead of a spiral is usually long in proportion to the diameter and length. For example, the lead of a 7/8-in.-diameter standard thread is 1/9 in. (having 9 threads per inch), and the lead of a standard 7/8-in. counterbore (cutterhead about 1 in. long) cut with a spiral flute is 10 in.

Setting up the machine for milling a spiral involves a knowledge of several mechanical principles. In the following pages the principles underlying the operation of spiral milling are first set forth as brief descriptions of the essential features. These features are then discussed in detail. To obtain a general survey of the subject read through carefully, and then, if possible while setting up and performing the operation, study each paragraph until the principle is thoroughly understood.

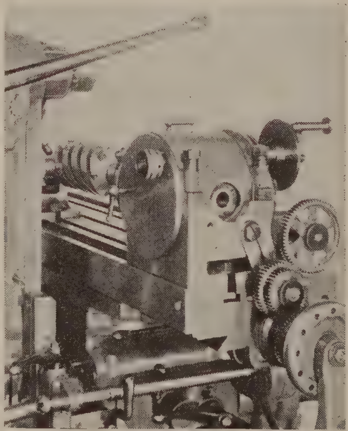

FIG. 253.—Milling a steep spiral with an end mill.

246. The Spiral.—A spiral is a line generated by the progressive rotation of a point around an axis. When the path of rotation is in a plane, it is called a plane spiral. A watch spring is an example of a plane spiral. If the convolutions of a spiral do not lie in a plane but form the shape of a cone it is known as a conical spiral. If this line is wound about a *cylinder* it is a *helix*, that is, what in machine-shop work is called a spiral, is, correctly speaking, a helix, but in the following text, common usage will be followed.

247. The Lead of a Spiral.—The lead of a spiral is the distance it advances in one revolution measured parallel with its axis, for example, if gearing is so arranged as to cause the work

to revolve once if it were fed 6 in., the lead of the spiral is 6 in. The length of the work or the length of the cut taken makes no difference; that is, a lead of 6 in. to one turn may be cut on work 3 in. long, or a spiral with a lead of 6 in. may be cut 12 in. long. In the first case, the groove will go one half around the work, and in the second case, it will go twice around the work. The lead, however, is the same in both cases.

In most of the spirals cut in the milling machine the lead is more than 1 in., usually several inches, therefore spirals are designated in terms of "lead in inches to one turn" or merely "lead," as 1.5-in. lead, 24-in. lead, etc.

248. Five Features of Spiral Milling. *First, the Gearing.*—Assume a cutter is set to mill a groove in a cylinder and that as the work is fed longitudinally under the cutter, it is at the same time given a uniform rotary movement. The groove will be a "spiral." In order to mill a spiral it is necessary to cause the work to *rotate* uniformly *on* its axis, while it is being *fed* in the direction *parallel* to its axis. The design of the universal milling machine permits of obtaining these two movements, in practically any desired ratio to each other, by means of gearing from the table feed screw to the worm-shaft of the index head, similarly as threads of different leads may be cut in a lathe by using different change gears. The selection and arrangement of the change gears as well as a description of the permanent gears in the index head will presently be explained.

Second Feature: Right-hand and Left-hand Spirals.—A spiral, like a thread, may be right-hand or left-hand and the same definition applies. A right-hand thread or spiral turns or "twists" to the right as it advances; the left-hand spiral turns in the opposite direction (Fig. 266). An easy way of telling whether a thread or a spiral is right- or left-hand is to hold it with the axis in a horizontal position and note the slant of the groove; if it slants *down* toward the right it is right-hand, if down toward the left it is left-hand. For example, observe that a twist drill has a right-hand spiral.

Third Feature: Setting the Table.—If it is required to mill a ½-in. semicircular spiral groove in a cylinder, a ½-in. convex cutter may be used. If the cutter is set up with its axis at right angles to the axis of the work, as shown in *a*, Fig. 254, and the work is fed on a spiral, the groove, instead of having a ¼-in. radius will have a radius about equal to one half the diameter of the cutter. This is shown in *b*, Fig. 254. In order to mill this spiral groove the same contour as the cutting

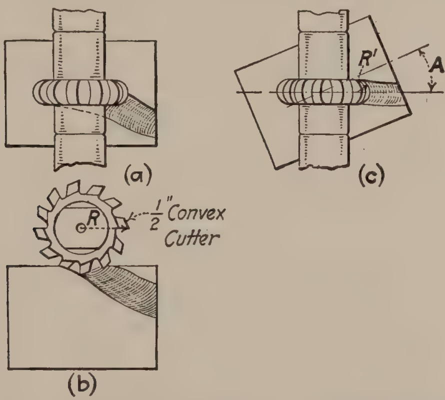

Fig. 254.—(*a*) Top view and (*b*) front view of spiral groove cut without swiveling the table. If the cutter is 2½ in. in diameter, the radius of the groove is about 1¼ in., approximately equal to *R*, the radius of the cutter. Note in (*c*), which represents the top view with the table swivelled to the angle of the helix *A*, that the radius of the groove is ¼ in., or equal to *R′*, the radius of the curve of the cutting edge.

edge of the cutter it is necessary (1) to swivel the table of the machine to a certain required angle, or (2) to set the cutter to this angle, using the universal milling attachment. The relative positions of the cutter and the work in either case (1) or (2) is illustrated in *c*. The angle is known as the angle of the helix (or spiral) and depends on *two* things, the *lead of the spiral* and *the circumference of the work*. How this angle is calculated will presently be explained.

Fourth Feature: The Shape of the Cutter.—Figure 255, *a*, represents a spiral groove with parallel sides, milled in a cylinder. This groove may be cut horizontally or vertically

with an end mill or a cotter mill as shown at *b*, but it will be impossible to produce such a groove of rectangular shape with a regular slotting cutter, because a cutter with parallel sides cannot fit in a curved slot. This is illustrated in *c*. The effect of attempting to use such a cutter for spiral milling is shown in *d*; the sides of the slot will be ragged and the shape of the slot will not be rectangular. Further, an angle cutter with a straight side should not be used to cut spiral flutes for

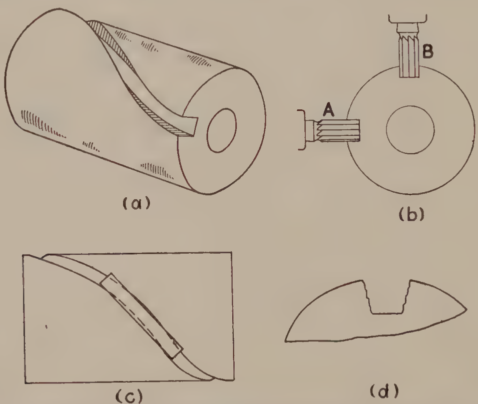

Fig. 255.—In (*a*) is shown a rectangular spiral groove, and (*b*) illustrates how this cut may be made with an end mill held horizontally as at *A* or in a vertical spindle as at *B*. If it were attempted to mill such a groove with a narrow plain milling cutter or a slotting cutter as in *C* the groove when cut would not be rectangular but would appear about as shown somewhat enlarged at (*d*).

the reason that the teeth on the straight side will not produce a clean smooth cut but will have an effect similar to that shown in *d* (Fig. 255).

It is, however, entirely feasible to use a cutter mounted on the arbor to mill a spiral groove, provided the side-cutting edges incline more or less toward each other, for example, a double-angle cutter, or a convex cutter, or a gear-tooth cutter may be used to cut a spiral because no part of the cutting edge of any tooth of such a cutter touches the work except when it is taking a chip (Fig. 265, page 322).

Fifth Feature: Circular Pitch and Normal Pitch.—The section (or shape) of a groove generated, or of the tooth formed

by spiral milling is *normal* (that is, of true form), only when viewed (measured) at right angles to the direction of the groove or tooth. The section of either as seen or measured on the end of the work is distorted; that is, the groove appears and is unlike the form of the cutter, and the tooth shape is correspondingly distorted when viewed at right angles to the axis of the work. This difference is shown graphically in Fig. 256, where ABC represents the circular pitch of a spiral gear, AB the tooth, and BC the tooth space. The dotted line ab shows the direction of the groove, and the line ADE at right angles to the side of the tooth at A represents the normal

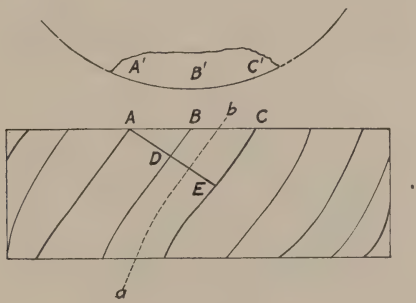

Fig. 256.

pitch of the gear. It is obvious that the width of the groove as viewed on the end BC is greater than the width as viewed at DE, and the depth being the same in both places the shapes are unlike. This feature is of extreme importance when milling spiral gears and must sometimes be considered when judging or gaging the shape of other spiral teeth or grooves.

Questions on Spiral Milling, I

1. What do you understand by the term spiral? Is a thread a spiral?

2. What are the points of similarity of a thread and a spiral? What is the chief difference between the helical groove of a thread and the helical groove of a spiral-milling cutter?

3. What is meant by the lead of a spiral? How is this distance usually expressed?

4. Why is it necessary, when milling a spiral, to cause the work to revolve slowly at the same time it is being fed?

5. How is the work caused to revolve while it is being fed?

6. Suppose the work would revolve once if it were fed 10 in., what would you change to give a lead of 20 in.?

7. The universal milling machine has a table with swivel construction. Why?

8. When is it necessary to set the table to an angle in spiral milling? When is it unnecessary?

9. State an easy way to tell a right-hand spiral from a left-hand spiral.

10. State why a regular slotting cutter cannot be used to cut a spiral groove of rectangular shape.

11. Is the angle of the flute or groove as measured on the end of a spiral milling cutter exactly the same as the angle of the cutter that produced it? Give reason.

249. The Gears Necessary for Spiral Milling.—Figures 257 and 258 show, respectively, a Brown and Sharpe index head and

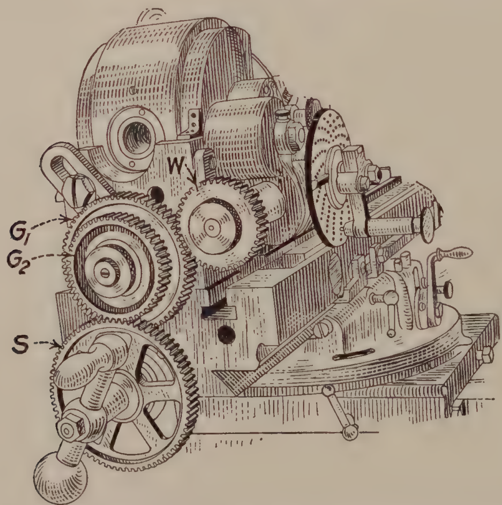

Fig. 257.—Brown & Sharpe index head arranged for spiral milling.

a Cincinnati index head arranged for spiral milling. It will be observed in either one, and as a matter of fact it is true in all standard universal milling machines, that motion from the table feed screw to the index head (gear W) is transmitted by spur gears. Certain of these gears are termed the "change gears" and are selected and arranged according to the spiral

desired. For example, if the gear W revolves at the same speed as gear S, a spiral with a lead of 10 in. will be cut; if W goes twice as fast as S a lead of 5 in. will result; if half as fast, a lead of 20 in. will result. Before learning how to calculate the sizes of these gears for the various spirals it will perhaps be best to determine how a movement of the gear W causes the work to move. This motion is transmitted by gears which are a permanent part of a spiral head.[1] For this reason they may properly be referred to as the spiral-head gearing.

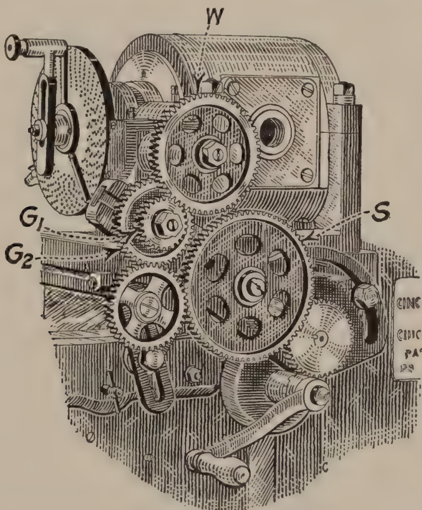

FIG. 258.—Cincinnati index head arranged for spiral milling.

250. Spiral-head Gearing.—The spiral head is a particularly ingenious and interesting mechanism. The underlying principle of the construction is the same for any standard make. The purpose is to cause the wormshaft (and consequently the work) to turn by power transmitted to the gear W (Figs. 257 and 258), without interfering in any way with the regular functions of the dividing head. To obtain this power movement, the index plate is (incidentally) caused to

[1] "Index head," "spiral head," and "dividing head" are used in different places to mean the same thing. A spiral head is an index head (or dividing head) which may be used for cutting spirals.

turn, consequently *it is necessary to disengage the index plate locking device when setting up for spiral milling.*

Because the shaft on which the gear W is mounted is at right angles to the wormshaft, the use of either bevel gears or spiral gears is necessary to transmit motion from the one to the other.

251. The Index Head with Bevel Gears.—The way in which *bevel* gears may be employed is illustrated in Fig. 259. Motion of the gear W causes motion of the miter gear B_1,

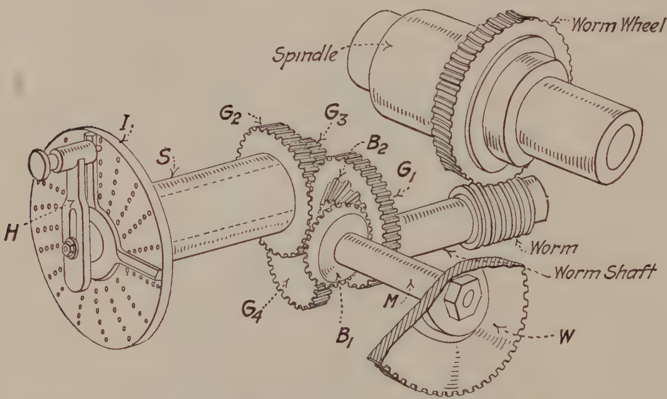

FIG. 259.—Spiral head gearing (Cincinnati). Motion transmitted from W through M to B_1 to B_2 to G_1 to G_2, through sleeve S to I to H, through shaft within S to G_3 to G_4, through wormshaft, worm, and wormwheel to spindle and work.

both being keyed to the shaft M; B_1 engages B_2 which is fastened to G_1; the gear G_1 engages G_2 which is fastened to the sleeve S, to which is also fastened the index plate I, consequently when the gears are in motion the index plate revolves. The index crank H and the gear G_3 are fastened to the same shaft, therefore if the index pin is in a hole in the plate and moves with the plate the gear G_3 moves. The gear G_3 engages G_4 which is keyed to the wormshaft and thus transmits motion to the worm and wormwheel. It will be observed that the pairs of gears B_1 and B_2, G_1 and G_2, also G_3 and G_4, are equal; therefore 40 turns of the auxiliary shaft M will cause one turn of the wormwheel.

Ordinarily, for indexing, only the gears G_3 and G_4 are used; the index plate is held in position by a stop and does not turn. When the index crank is turned its shaft turns freely through the sleeve S, moving the gears G_3 and G_4 and causing the worm and wormwheel to move, thus indexing the work the required amount.

252. The Index Head with Spiral Gears.—In the cut (Fig. 260) is shown the arrangement of the gearing in an index head

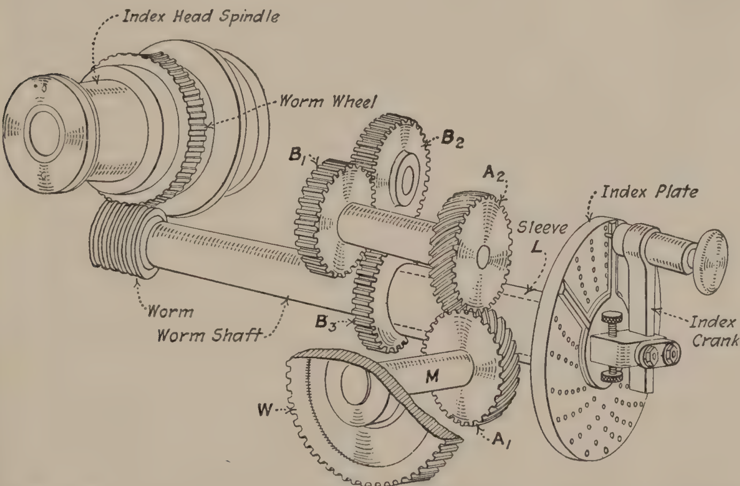

FIG. 260.—Spiral head gearing (Brown & Sharpe). Motion transmitted from W through M to A_1 to A_2 to B_1 and B_2 (idler) to B_3, through sleeve L to index plate to index crank to wormshaft, worm, wormwheel, spindle, and work.

in which *spiral gears* are used to transmit the motion at right angles. The construction of the head is more compact than the cut indicates. This cut has been made with the idea of showing the arrangement more clearly.

Motion of the gear W on the shaft M is transmitted to the spiral gear A_1 to the other spiral gear A_2 to spur gear B_1 to intermediate B_2 to B_3. The gear B_3 and the index plate are fastened to the sleeve L. Therefore, when B_3 revolves the index plate revolves and when the index pin is in, the index

crank is carried around with the plate, and since the index crank is fastened to the wormshaft, this operates the worm and wormwheel. Remember when setting up that the *stop pin* must be withdrawn.

In the above arrangement, it will be noted that simple indexing of the piece being milled on a spiral is accomplished in the usual way. (Pull out the index pin, turn the index handle, and the wormshaft turns in the sleeve L and causes the work to turn the required part of a revolution entirely independent of the gearing for the spiral.) The idler gear B_2 is in the swivel center of the head, and tilting the head in no way affects the engagement of the gears. The gears all have the same number of teeth so that 40 turns of W will cause one turn of the wormwheel.

In connection with a study of the gearing which may be regarded as a permanent part of the index-head mechanism, there are three outstanding features.

First, the operation of indexing is entirely independent of the spiral mechanism, for example, after one groove of a spiral mill is cut the table is run back and the work indexed in the usual way for the next groove.

Second, the arrangement of the gears in the head is such that when not in use they in no way interfere with tilting the head, or with either simple or direct indexing.

Third, one turn of the auxiliary shaft on which the gear W is mounted causes one turn of the wormshaft and $\frac{1}{40}$ of a turn of the work; in other words, the operation is exactly the same as if the gear W were mounted direct on the wormshaft, and in any discussion of the mechanism and in the calculations for the change gears for cutting any spiral, the gear W is spoken of as the "gear on worm."

253. Change Gears for Spiral Milling.—In Figs. 257 and 258 the gear S known as the *gear on screw* is keyed to the feed screw. G_1 and G_2 are respectively *first gear on stud* and *second gear on stud* (or first intermediate and second intermediate). They are both keyed to a sleeve which rotates freely on a stud which is fastened in an adjustable bracket, and form the com-

pound between S, the gear on screw, and W which in spiral milling is known as the *gear on worm.*

Thus a movement of the feed screw, besides causing the table to feed, may cause the work to revolve if gears are arranged to transmit motion from the feed screw to the worm shaft. The gears S, G_1, G_2, and W are the change gears. Twelve change gears are regularly furnished, and by using different combinations of gears, the ratio of the rotary movement of the work to the longitudinal movement of the table can be varied, and spirals of various leads may be cut. Introducing an idler serves to change the direction of the driven gear, consequently spirals may be either right-hand or left-hand.

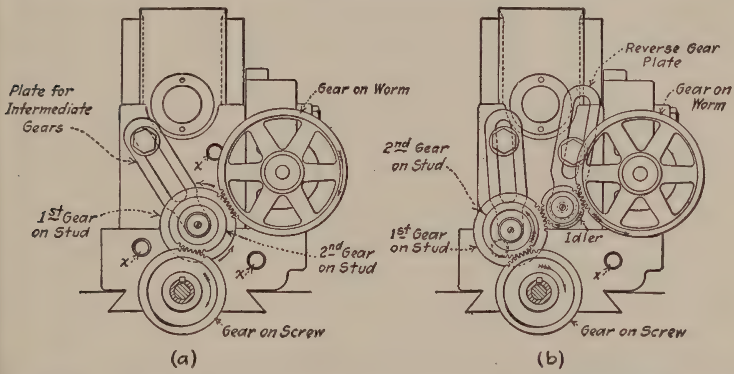

FIG. 261.—Brown & Sharpe change gears arranged (*a*) for right-hand spiral, and (*b*) with idler introduced for cutting left-hand spiral.

The manner of arranging the change gears for spiral milling on the Brown & Sharpe milling machine is indicated in Fig. 261; *a* shows the arrangement when no idler is used, and *b*, when an idler is used.

It will be noted that the gears on the stud and also the idler gear are mounted on adjustable brackets. Tapped holes (x) are provided in the back of the index head and in the end of the table for the cap screws used for holding these brackets.

The Cincinnati dividing head arranged for milling a spiral is illustrated in Fig. 258. The driving mechanism consists of 12 change gears and an adjustable bracket or segment

on which the necessary gears to transmit motion between the feed screw and the auxillary wormshaft may be arranged.

It will perhaps be well to call special attention here to the following: In the Cincinnati milling machine, as in the Brown and Sharpe, the first intermediate drives the gear on worm, but its position on the stud is reversed, it is the *second* one put on. This may be true also of certain other machines. However, if the machinist who is setting up the machine understands which gears are *driving* gears and which are *driven* he will have no trouble in setting any milling machine for the given spiral. The gear on the screw *S* is the initial *driving* gear and the "gear on worm" *W* is the final *driven* gear of the change-gear train.

It will be observed that the four change gears make up a compound gear train; that is, two are driving gears and two are driven gears. Compound gearing is usually employed because with a given number of change gears a much larger range of combinations is possible than can be obtained with a simple gear train, and also, the very short center distance between the gear on screw and the gear on worm makes compounding practicable for most of the leads to be cut.

The idler is neither a driving gear nor a driven gear. It is an *idler* gear and serves to change the direction of the gears which follow it in the train. The use of the idler varies with different machines; in some it is used when cutting right-hand and in others when cutting left-hand spirals.

254. Calculating the Gears for Spiral Milling.—In spiral milling if equal gears are used on the feed screw and worm, and these gears connected by an intermediate (two equal gears may be used on the stud to act as a single intermediate), the shaft *M* (Figs. 259 and 260) will revolve at the same speed as the feed screw. Therefore, when the feed screw revolves 40 times, the wormshaft revolves 40 times and *the work revolves once.* At the same time, since the screw revolves 40 times, the table moves a certain distance, usually 10 in. In spiral milling this distance is known as the "*lead of the machine.*" (Most milling machines have a ¼-in.-pitch feed screw, and 40

revolutions of the feed screw will feed the table $40 \times \frac{1}{4}$ in., or 10 in.)

In spiral milling, the formula for calculating the gears to cut any spiral is similar to the formula for calculating the gears for thread cutting in a lathe, the constant in spirals being the "lead of the machine." The formula may be expressed as a proportion thus: the lead of the machine is to the lead of the spiral required as the product of the driving gears is to the product of the driven gears. Expressing the ratios as fractions:

$$\frac{\text{Lead of machine}}{\text{Lead of spiral desired}} = \frac{\text{driving gears}}{\text{driven gears}}$$

To illustrate the calculations two examples are given:

Example 1.—Spiral with a lead of 12 in. required.

Using the formula and substituting values

$$\frac{\text{Lead of machine (10)}}{\text{Lead of spiral required (12)}} = \frac{\text{driving gears}}{\text{driven gears}}$$

That is,

$$\text{The fraction } {}^{10}\!/_{12} = \text{ratio } \frac{\text{driving gears}}{\text{driven gears}}$$

Now if a simple gear train (one driving and one driven gear) were to be used and a 10-tooth gear for the screw and a 12-tooth gear for the worm were available such an arrangement could be used. However, no such gears are at hand, and further, it is desired in this example to use four gears as a compound gear train because in most cases, if not in this, a compound gear train is advisable.

In order to select these gears the fraction ${}^{10}\!/_{12}$ is split into two fractions whose product equals ${}^{10}\!/_{12}$, for example $\frac{5}{4} \times \frac{2}{3}$, the terms of which will represent the two pairs of change gears.

If it were possible to obtain and use gears with 5 teeth and 2 teeth, they would be the driving gears and the 4-tooth and 3-tooth gears would be the driven gears. Of course, this is impossible, therefore both the numerator and denominator

of either fraction ($\frac{5}{4}$ and $\frac{2}{3}$) are multiplied by any number whole or mixed,[1] that will give a numerator and denominator that corresponds to the numbers of the teeth on two of the available change gears.

Thus, multiplying both the numerator and denominator of the first fraction $\frac{5}{4}$ by 8 for trial, and of the second fraction $\frac{2}{3}$ by 24 for trial gives

$$\frac{5 \times 8}{4 \times 8} = \frac{40}{32} \qquad \text{and} \qquad \frac{2 \times 24}{3 \times 24} = \frac{48}{72}$$

or

$$\frac{5 \times 2}{4 \times 3} = \frac{40 \times 48}{32 \times 72} = \frac{\text{driving gears}}{\text{driven gears}}$$

That is, gears 40 and 48 may be used for the driving gears and 32 and 72 for the driven gears.

These gears may be arranged in the B. & S. machine for example as:

72 gear on worm (driven gear)
40 first gear on stud (driving gear)
32 second gear on stud (driven gear)
48 gear on screw (driving gear).

Or they may be arranged otherwise *if* the driving gears are arranged to drive and the driven gears are arranged to follow.

Example 2.—Spiral of 27-in. lead required.

$$\frac{\text{Lead of machine (10)}}{\text{Lead of spiral desired (27)}} = \frac{\text{driving gears}}{\text{driven gears}}$$

$$\frac{10}{27} = \frac{2 \times 5}{3 \times 9} = \frac{32 \times 40}{48 \times 72}$$

72 gear on worm (driven gear)
32 first gear on stud (driving gear)
48 second gear on stud (driven gear)
40 gear on screw (driving gear).

NOTE.—Remember when using the above formula that the gear on the screw is the initial *driving* gear.

[1] Multiplying both the numerator and denominator of a fraction by the same number does not change the value of the fraction.

As a matter of fact, from a practical standpoint, the cards furnished with the machine will show the gears to use and the angles to set the table for a great variety of spirals. Further, all leads possible with the combinations of gears that may be used have been calculated and published by Brown & Sharpe Manufacturing Co. and also by the Cincinnati Milling Machine Co. However, the man who is always satisfied to let someone else do his thinking for him is always cheap help. What would he do if one of the gears were lost or broken?

255. The Angle of the Helix or Spiral.—As previously stated (paragraph 248) in order to cut a spiral otherwise than with an end mill, it is necessary to set the table or the cutter to a certain angle, that is, to the angle of the helix (or spiral) being cut.

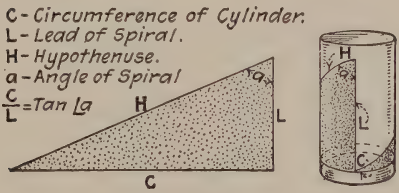

Fig. 262.

The development of a spiral, in other words the path of the spiral, may be represented by the path of the hypotenuse of a paper right-angle triangle (Fig. 262), when wound about a cylinder as shown. The adjacent sides L and C must equal respectively the *lead* of the spiral and the *circumference* of the cylinder, and the side L is parallel to the axis of the cylinder. The angle included between the sides H and L is the angle of the spiral and this is the angle to which the table must be set, or if using the universal milling attachment the angle to which the cutter must be set.

The angle of the spiral may be ascertained in two ways; graphically that is, by making a drawing of a right triangle similar to that shown in Fig. 262, L being equal to the lead, and C equal to the circumference of the work. The angle a may be measured with a protractor.

The second method, which is more accurate and often more convenient, involves mathematical calculations and the use of a table of tangents.

The calculations for the parts of a helix (or "spiral") are made with the use of trigonometric tables.[1] In the right triangle Fig. 262 the circumference of the cylinder corresponds to the *side opposite* the angle, and the lead corresponds to the *side adjacent* the angle. Hence the following rules:

RULE I.—To find the angle of the spiral having given the circumference of work (pitch circumference in spiral gears) and the lead: Circumference divided by lead equals the tangent of the spiral angle or

$$\frac{C}{L} = \tan \text{ angle } a$$

Example.—Diameter of blank = 3 in. (*circumference* equals 9.42); lead = 24 in. What is the angle of the spiral?

Solution.—$\frac{9.42}{24} = 0.392 = \tan 21°25'$, or $21\frac{1}{2}°$ (near enough).

RULE II.—To find the lead having given the circumference of blank and the spiral angle: Divide the circumference by the tangent of the angle, or

$$L = \frac{C}{\tan \text{ angle } a}$$

Example.—Diameter equals $3\frac{1}{2}$ (circumference equals 10.09); angle of spiral equals 26 deg. What is the lead?

Solution.—Tangent of angle of 26 deg. equals 0.488. Dividing circumference 10.90 by 0.488 equals 22.5, or lead equals $22\frac{1}{2}$ in.

Setting the Table for Right-hand and Left-hand Spiral.—For a *right-hand spiral* move the zero line on the swivel plate to the right of the zero line on the saddle; in the opposite direction for a *left-hand spiral.*

[1] For formulas and tables see pages 493 to 497. For simple explanation of shop trigonometry see: "American Machinist's Handbook" (McGraw-Hill Book Company, Inc.); Burnham's "Mathematics for Machinists" (John Wiley & Son, Inc.).

256. Milling Steep Spirals.—It is often advantageous to use the compound vertical attachment or the universal milling attachment, especially when milling steep (short-lead) spirals (Figs. 263 and 264). When this attachment is used for spiral milling, the table is not swiveled, but it will be necessary to set the cutter to the angle of the spiral by swiveling the attachment. The work is brought into its proper position with reference to the cutter, *after the cutter is swiveled.*

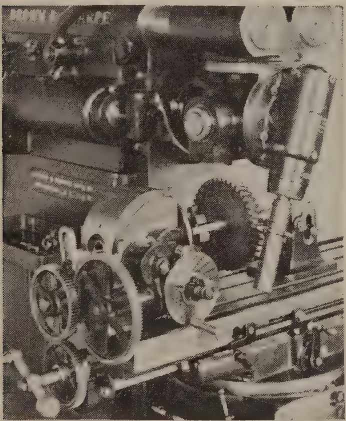

Fig. 263.—Cutting teeth in a spiral gear, using compound vertical milling attachment swung to angle of spiral. Table is not swiveled.

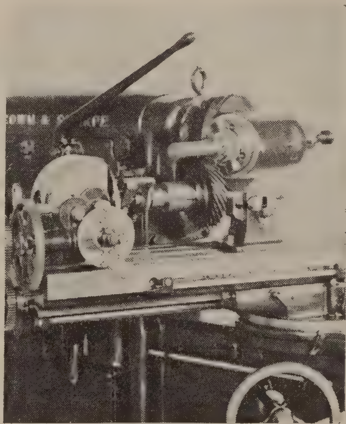

Fig. 264.—Cutting teeth in spiral gear with vertical attachment swung up 90 deg. and table swiveled to angle required.

The rack milling attachment or the vertical milling attachment may be used for milling short-lead spirals. When using either of these attachments the worktable is swiveled to an angle equal to the *compliment* of the angle of the spiral.

257. To Use the Card Furnished with the Machine.—(Card marked, "Table of Approximate Angle for Cutting Spirals" or "Table of Change Gears, Angles, and Leads for Cutting Spirals.")

1. To find the gears to use:

In column marked "lead in inches" find the required lead, and in line with the lead, the four gears that will give this

lead are shown. The position of each gear is shown at the top of its column—as "gear on worm," "first gear on stud," "second gear on stud," and "gear on screw."

2. To find the angle at which to set the table:

Near the top of the card under the heading "Diameter of Work" or "Diameter of Cutter, Drill, or Mill" are several columns captioned by figures representing various diameters from $\frac{1}{8}$ to 6 in. In these vertical columns are figures representing the various angles to which the table must be swiveled to give the proper setting of a particular diameter of work for any spiral. The number of degrees the table must be swiveled is found where the horizontal column to the right of the "lead" meets the vertical column under the "diameter."

Example.—Work, $2\frac{1}{2}$ in. in diameter; lead, 22.50.

1. Find under "lead in inches to one turn" 22.50. In the same line are four gears; 72, gear on worm; 28, first gear on stud; 56, second gear on stud; 64, gear on screw.

2. Lay a card or a rule just under the horizontal column of figures to the right of the lead 22.50, then follow down column under $2\frac{1}{2}$ diameter until the figure opposite 22.50 is reached and find that the table should be set around $19\frac{1}{4}$ deg.

Questions on Spiral Milling, II

1. What is the purpose of the "change gears" in spiral milling? How many are there?

2. What do you understand by "the spiral-head gearing?"

3. Why are either bevel gears or spiral gears used in the spiral-head gearing?

4. Why is it necessary to withdraw the stop pin or disengage the index plate locking device, whatever it may be, when cutting a spiral?

5. Make a sketch which will show the way in which motion is transmitted from the table-feed screw to the spiral-head spindle.

6. Set up the machine for any convenient lead of spiral. In the change gear train which is the initial driving gear? Is there a compound of two gears used? Is an idler used? Which is the final driven gear?

7. As for the set up in the preceding question. Divide 10 times the product of the driven gears by the product of the driving gears. What is the answer equal to?

8. If it were possible to transpose the driving gears and still get the proper engagement of gears in the train, would this change the spiral? Explain.

9. Suppose the card furnished with the machine calls for certain gears to cut a given lead and one of the gears is lost, what could you do?

10. The card furnished with Brown and Sharpe milling machine calls for the gears 56, 32, 40, and 100 to cut a lead of 7 in. The gears 56, 40, 32, and 64 if properly arranged may be used? How should they be arranged?

11. In the first case (question 10) 32 is a driving gear and 40 is a driven gear. Is this true in the second case? Explain.

12. On the card furnished with Brown and Sharpe milling machine, the angle of the spiral for a lead of 7 in. on work 1 in. in diameter is given as 24½ deg., and for work 2 in. in diameter the angle is 42 deg. Cut out triangles as explained in paragraph 255 and check results.

13. Cut out a triangle to show the angle of the spiral for a lead of ¼ in. on work 2 in. in diameter. How does this angle compare with the angle for work of the same diameter but half the lead (question 12)?

14. State the *two* things that determine of the angle of the spiral.

15. Frequently a certain angle of spiral is required on a given diameter. How would you find the lead? How would you calculate the gears to use?

THE OPERATIONS OF CUTTING A SPIRAL

258. Example Selected: Spiral Milling Cutter.—Operations in spiral milling which are not uncommon in most machine shops and which offer excellent practice are cutting the flutes in spiral milling cutters, spiral end mills, and counterbores. These operations involve less mathematics than cutting either cams or spiral gears,[1] but they do require the same knowledge of spiral milling and as much if not more skill in the setup.

The reason that the setup for cutting a spiral mill is more difficult is because the flute is not symmetrical, as is the cam groove or the gear-tooth space. To set the cutter for a spiral gear, for example, it is only necessary to set the cutter central with the blank before swiveling the table to the required angle, while to set a double-angle cutter to produce either a radial tooth, as is usually required on finishing cutters, or a

[1] For extended descriptions of the milling of spiral gears and cams, see the following: "A Treatise on Milling and Milling Machines," published by Cincinnati Milling Machine Co.; "Treatise on Gearing," and "Treatise on Milling," published by Brown & Sharpe Manufacturing Co.

tooth with 10- or 15-deg. rake for roughing cutters, it is necessary to offset the work under the cutter a certain distance. Since the distance the work is offset depends (1) on the angle of the cutter, (2) the diameter of the blank, (3) the number of teeth, and (4) whether a radial tooth face or an undercut tooth face is required, no set rule for the offset can be given. It is best to lay out lines indicating the faces of two adjacent teeth and proceed carefully to cut to the layout. (Explained page 325.)

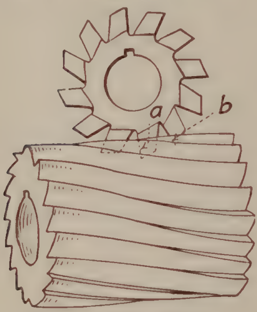

FIG. 265.—Hold a double-angle cutter in the groove of a spiral milling cutter with the cutting edges *a* vertical and touching the sides of the groove, then observe the amount of clearance (space) between the cutting edges *b* and the groove.

259. Reason for Double-angle Cutters.—When an angular shaped groove is desired, as in a spiral milling cutter, it is impossible to produce a radial tooth or a smooth surface with an angular cutter because such a cutter has one straight side and will act similarly to the cutter *c* in Fig. 255. A double-angle cutter should be used. The groove clearance of a double-angle cutter is illustrated in Fig. 265. It will be noted that after the slot is cut to depth as at *a* that the tooth back of *a* does not touch the groove at all. The fact that the angular teeth in this way clear the groove already cut makes it possible to use this kind of cutter for spiral milling. For fluting spiral milling cutters 2½-in. in diameter or more and up to a 25-deg. spiral angle a double-angle cutter with a 12-deg. angle on one side and either a 40-, 48-, or 53-deg. angle on the other side may be used. To cut a short lead spiral on a small diameter, for example, a 4.26 lead on a 1 in. end mill, will require a greater angle than 12 deg. on the cutter. It will depend, of course, on the shape of the tooth desired whether a cutter with an included angle of 52, 60, or 65 deg. is used. In any case the steep side should form the face of the tooth.

260. Use of Right-hand and Left-hand Double-angle Cutters.—A cutter should be selected, right-hand or left-hand

as the case may be, which in operation will free the steep side of the groove, that is, the blank being milled should turn in a direction away from the 12-deg. side of the cutter. This will give a cleaner, smoother surface to the front (or face) of the tooth being milled. The correct setup for milling right-hand and left-hand spiral cutters is shown in Fig. 266.

261. Setting the Cutter for Spiral Milling.—In the universal milling machine, the *axis* of the cutter and the *pivot center* of the table are in the same vertical plane. It is only in this

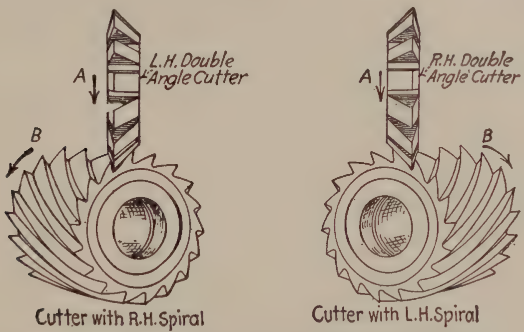

Fig. 266.—Illustration of difference in the setting of the table and also in the cutter used when milling right-hand and left-hand spirals. Both views are shown as from the footstock end of the table. Arrow *A* denotes the direction of the cutter, and arrow *B* the direction of the rotation of the blank as the spiral groove is being milled.

plane that the cutter cuts its full depth (or its shape) in the work.

This is one of the most important points to remember in setting up for spiral milling. Suppose the machinist sets up to split a line when the edge of the blank is, say, a quarter of an inch in front of the axis of cutter. Not only is the cut made deeper when the work is fed the quarter of an inch, but the work *rotates* at the same time it is *fed* and, of course, the line rotates with the work and its relation to the cutter is changed.

When milling spiral flutes that are symmetrical, that is, alike on both sides (for example, the teeth on a spiral gear), *care must be taken to set the work centrally under the cutter before the table is swiveled.*

In setting up for spiral milling when the groove is not symmetrical, for instance the flute in a milling cutter, it is customary to draw lines on the end of the first blank to be milled which will indicate the relative positions of the faces of two adjacent teeth. These lines are scribed after the blank is in position between centers as will be explained later. The end of the blank is then arranged directly over the pivot center of the table, that is, directly under the axis of the cutter; next the table is swiveled, and then the work may be adjusted on its axis or crosswise or vertically (but *not* longitudinally) under the revolving cutter until the cut made is according to the layout.

The greater the angle of the spiral the further the worktable must be moved away from the column in order to allow the table to be swiveled the required amount. Also the cutter must be arranged on the arbor practically over the pivot center of the table. Since guessing at the position of the cutter on the arbor is likely to cause delay, the following procedure is advisable:

1. Place the work between centers.

2. Swivel the table to the angle of the spiral.

3. Move the table laterally ("cross-feed") until there is ½ in. or so clearance between the table and the column.

4. Tighten the cutter on the arbor in substantially its proper position over the work. Now it is assured that the cutter is in the right place on the arbor.

5. Bring the table back to straight (zero) and set the end of the work under the axis of the cutter. This is in order to have the cutter in such a position, when the work is being adjusted, that the full depth and exact shape of the groove that will be cut may be noted. It is easier to judge the proper setting when the table is straight.

6. Swivel the table once more to the angle of the spiral, and tighten the clamping screws.

7. Proceed to make the necessary layout and adjustments as explained in the following paragraphs.

262. The Operation of Setting a Double-angle Cutter.—Many spiral-milling cutters are milled with a 48–12-deg. angle

cutter. Assuming such a cutter is used, the method of procedure for layout, etc., would be as follows: Apply blue vitriol on the end of the blank and with a surface gauge, set to height of index centers, scribe a line (1), as shown in *a*, Fig. 267. Index for one tooth space and scribe another line (2) as shown in *b*, these two lines represent the faces of two adjacent teeth. When cutting the groove between these two teeth, the cutter and the work must be arranged in such a way that one side of the cutter (the 12-deg. side) will split one radial line, and the other side of the cutter will leave an uncut space, equal to the land required, between the groove and the line

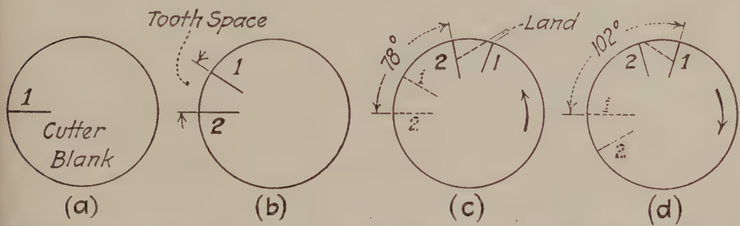

FIG. 267.—Illustrates method of laying out two adjacent tooth-face lines and indexing these lines to their proper position. (These views are from footstock end with index head on left end of table, as in Brown & Sharpe machine).

Remember when indexing for a certain number of degrees that one turn of the index handle moves the work 9 deg.

representing the face of the next tooth. This is shown in *c* where the lines (1) and (2) have been rotated to position under the cutter. When rotating the blank to bring the lines (1) and (2) in position it makes a great difference whether a right-hand or a left-hand spiral is being milled. This is illustrated in *c* and *d* (Fig. 267). If a right-hand spiral is to be cut, the work will have to be revolved as illustrated in *c*. If the line (2) is moved (indexed) 78 deg. (90 deg. minus 12 deg.) it will bring this line in position for the radial face of the tooth. If the work is moved transversely and vertically until the cut made splits line (2) and approaches close enough to line (1) to leave the amount of land desired on the tooth, then the setting is correct.

If a left-hand spiral is to be cut the method of procedure after drawing the two lines as illustrated in *d* is as follows:

Rotate the work *back* one tooth space to bring the line (1) on center (as it was originally, see *a*), then rotate it forward again 102 deg. (90 deg. plus 12 deg.) (see *d*, Fig. 267). This will bring the line (1) in position for the radial face of the first tooth and line (2) one tooth-space distant so that the amount of the land may be easily judged.

NOTE.—Above are directions which apply to Brown & Sharpe milling machine and all machines where the index head is on the left end of the worktable. When head is on the right end of the worktable as in the Cincinnati milling machine, the directions for layout for right-hand and left-hand spiral milling cutters are reversed.

263. A Typical Spiral-milling Job, Step by Step.—Required to cut a right-hand spiral milling cutter 2½-in. in diameter, 18 teeth, radial face, $\frac{1}{32}$-in. land, 12-deg. angle of spiral with 60 deg. (48–12 deg.) double-angle cutter.

1. Obtain mandrel, dog, arbor, cutter (48–12 deg.), surface gauge, blue vitriol, etc. It is much better to have a special shouldered mandrel with a key and a nut for holding the cutter. It should be long enough to obviate any chance of the cutter's running into the dog.

2. Arrange the work on the mandrel.

3. Thoroughly clean and dry the hole in the spindle, and the shank of the arbor, and drive (or draw) arbor home *tight*.

4. Arrange sector with correct number of spaces between the arms, and *withdraw stop pin*.

5. Arrange proper change gears and try hand feed *to be sure spiral mechanism operates freely*.

$$\text{Lead} = \frac{\text{circumference}}{\text{tan of spiral angle}} = \text{in this case } \frac{2.5 \times 3.14}{\text{tan of angle of } 12°}$$

$= \dfrac{7.85}{0.213} = 36.8$ in. The nearest lead with available gears on Brown & Sharpe milling machine is 37.04; on Cincinnati milling machine nearest lead is 36. Either is near enough.

6. Loosen swivel clamping bolts, temporarily set table to angle of spiral and feed crosswise until table clears face of column by about half an inch.

7. Arrange cutter blank between centers, and feed table until end of blank is approximately under axis of cutter arbor.

8. Arrange cutter approximately central (crosswise) over end of blank and tighten cutter on arbor securely.

9. Swivel the table back to straight (zero) and feed longitudinally until end of blank is exactly under axis of cutter.

10. Put blue vitriol solution on end of blank where lines are to be scribed.

11. With point of scriber on center draw radial line (1) (Fig. 267). Index one tooth space and draw line (2) then index as per directions given in paragraph 262, according to the arrangement of the head, left or right end of table.

12. Swivel table to correct angle and tighten.

13. Cut tooth space to depth, splitting tooth-face line and leaving 1/32-in. land. To do this it should only be necessary to adjust the work vertically and crosswise. The index handle and the longitudinal table feed should not be touched.

14. Either two cuts (roughing and finishing) or one may be taken as seems advisable. When table is adjusted for the finishing cut set the graduated collars on the cross-feed and vertical feed at zero.

NOTE.—The difference between the normal pitch and circular pitch (paragraph 248) as regards the line (1) in this case is practically negligible.

Cautions.—Be especially careful when milling spirals to have the work tight on the mandrel, the cutter arbor tight in the spindle, and the dog securely fastened.

Be sure the dog has plenty of room to turn and will not bring up against the arbor at the end of any cut.

Remember to lower the table before running back and to raise it again before starting the next cut.

Questions on Spiral Milling, III

1. Do you know how to read the card furnished with the machine? Are you satisfied merely to know how to read it?

2. What is a double-angle cutter? Why is a double-angle cutter better for milling spirals than a cutter with one angle?

3. Make a sketch that will show why a double-angle cutter must be "offset" from center in order to cut a radial tooth.

4. State why it is impossible to give a rule for the amount of offset?

5. Why are double angle-cutters made in both right-hand and left-hand forms? How do you tell one from the other?

6. What do you understand by a vertical plane? When is the end of the work in the same vertical plane as the axis of the cutter?

7. If a cutter is set central over the work before the table is swiveled, is it central after the table is swiveled? Give reason.

8. Is it easier to set the cutter central before or after the table is swiveled?

9. Why is it advisable to arrange the work, swivel the table, and feed the table laterally until it is about half an inch from the column before arranging and tightening the cutter on the arbor?

10. When laying out the lines of two adjacent teeth on the end of a spiral-milling-cutter blank, why are the lines rotated either 78 deg. or 102 deg.?

11. What is the difference between right-hand and left-hand spiral milling cutters?

12. Make a sketch similar to Fig. 267 to show the method of laying out a right hand spiral milling cutter when using a milling machine with the head on the right-hand end of the table.

THE GRINDING MACHINE

CHAPTER XIV

GRINDING-MACHINE CONSTRUCTION

264. Introduction.—A far greater advance in design, construction, and use has taken place during the past few years in the grinding machine than in any other machine-shop tool. Until recently the grinding machine was regarded as a toolroom machine, particularly useful only for finishing hardened steel. It is, however, now recognized as one of the most important machine tools for manufacturing purposes. This is owing to the remarkable development of the machine itself, and also of the abrasive wheels used, as the means of producing very accurate and beautifully finished surfaces, economically. The work may be any of the metals used in machine construction, such as cast iron, wrought iron, bronze; also hardened or unhardened steel of whatever variety.

Perhaps because of its comparatively rapid development, grinding is one of the operations least understood by the otherwise intelligent machinist, and this fact should be an added incentive for the ambitious beginner to gain as much knowledge as possible of the grinding machine, the characteristics of the various abrasive wheels, and the methods employed in grinding. Manufacturers are very willing to send catalogues of their machines to foremen or instructors for the purpose of placing them in the hands of those interested. Articles on this interesting subject are frequently published in the trade journals. It is recommended that the beginner obtain and read a catalogue or better still, an operator's manual and any other information he is able to get concerning the machine he is going to operate. He will thus acquire a

broader understanding of that particular machine and also a general knowledge, since the basic principles of the essential mechanisms are practically the same in all grinding machines of a given type. The young man who will study and reason, observe what others are doing, ask sensible questions, and take advantage of every chance for experience will soon get the information he is after.

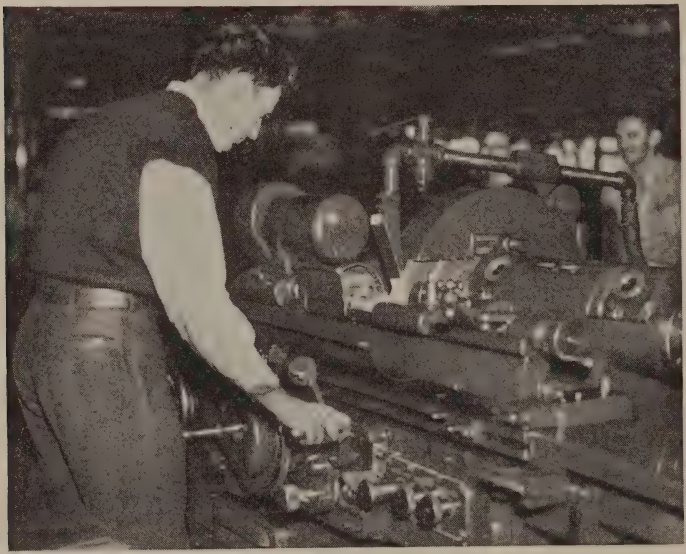

Fig. 268.—Plain grinding machine, with hydraulic table traverse and cross-feed mechanism. (*Courtesy of Cincinnati Milling Machine and Cincinnati Grinders, Inc.*)

The function of the grinding machine is, like every other machine tool, the removal of metal by means of a suitable cutting tool. For the same reason that there are various types of lathes, milling machines, drilling machines, etc., there are various types of grinding machines. Just as there are different shapes and kinds of milling cutters for various purposes, there are several shapes and a variety of kinds of grinding wheels.

The cutting tool used is a grinding wheel or "abrasive" wheel, revolving at a high rate of speed. This wheel is made up of small sharp-edged fragments of a very hard substance cemented or "bonded" together. Very probably the boy in the shop as he sharpens a lathe tool or a drill in the "wet grinder" imagines that the wheel rubs off the steel. It may be that it does if the wheel is dull, that is, if the projecting edges have been rounded by continued grinding; but when the wheel is sharp it *cuts*. The chips are very small but they are real chips, nevertheless.

A few types of grinding machines are illustrated and briefly described in the following three or four pages. One standard machine is illustrated with the parts numbered and named.

Get acquainted with the machine you are running; learn the function of the various handwheels and levers, go back of the handles; find out what they operate. Adjust the feed for a given amount; study the feed mechanism. Learn how the stroke is adjusted for length and position and how it is reversed. Oil the machine carefully. As soon as convenient, learn how to adjust the wheel-spindle bearings. Unless these bearings are properly adjusted poor grinding will result. It may be this machine you are running is all right, but what about some other one? It is better to get information concerning elementary principles when you are recognized as a beginner.

Grinding machines are classified as to kind as plain (cylindrical), internal, surface (meaning plane surface) and universal. To these may be added the centerless grinder (see page 401). Certain grinding machines are named according to the purpose for which they are made, for example, cutter and reamer grinder and drill grinder. These two are toolroom machines and are standard equipment. Special manufacturing machines such as are used for grinding rolls, rings, car wheels, automobile crankshafts and camshafts are adaptations, more or less, of standard types.

Grinding machines are classified as to size usually by number, by some manufacturers according to the maximum size

(diameter and length) of the work which the machines will accommodate.

265. The Plain Grinding Machine (Fig. 269).—A machine for grinding, outside only, cylindrical or tapered work. Stock sizes range from 6 by 32 in. to 20 by 168 in. In commercial practice this machine has largely superseded the lathe for finishing cuts because accuracy is obtained easier, quicker and cheaper. In addition the same degree of accuracy and

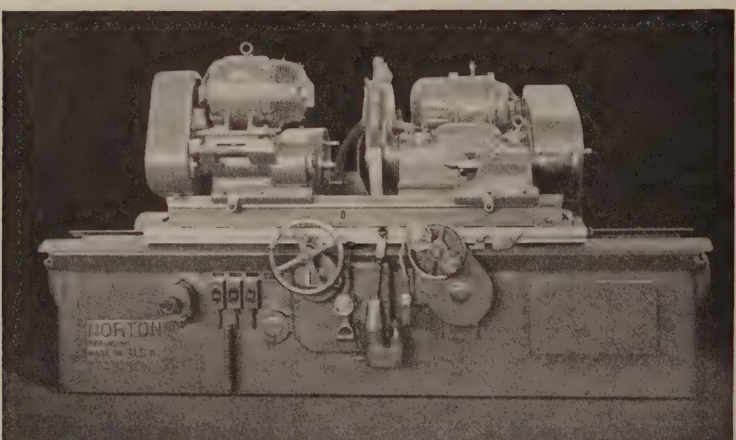

Fig. 269.—Plain grinding machine with hydraulic table traverse. Stock sizes up to 14 by 96 in. One electric motor drives the hydraulic and lubricating oil pumps, a second the work, and a third the wheel spindle. (*Courtesy of Norton Company.*)

economical production is obtained on hardened steel as on the softer metals, which fact has made possible the introduction of many heat-treated steel parts into machine construction that would otherwise have been impossible. For a description of centerless grinding machine see page 401.

266. Internal Grinding Machines.—Two types of grinding machines for finishing round holes are shown in Figs. 270 and 271. The machine shown in Fig. 270, and also the internal-grinding attachment illustrated on page 397, are for grinding holes in work as the work *revolves*, and holes of any size

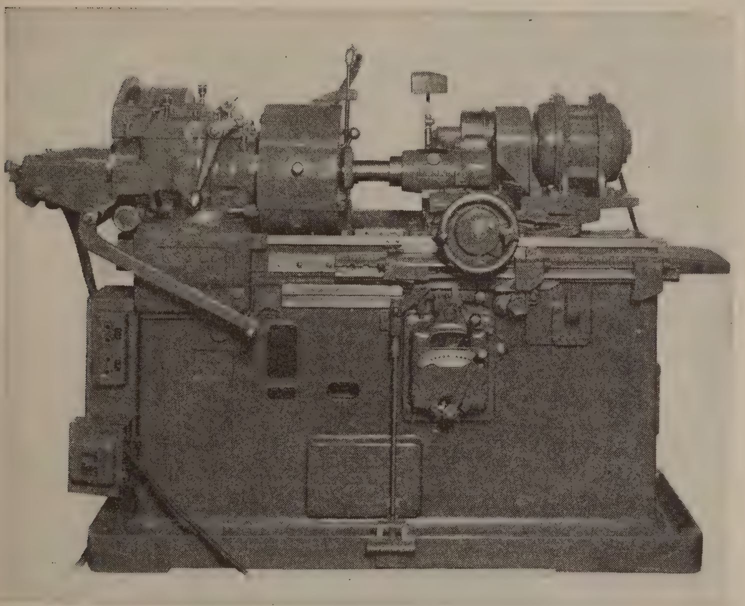

FIG. 270.—Internal grinding machine. (*Courtesy of The Heald Machine Company.*)

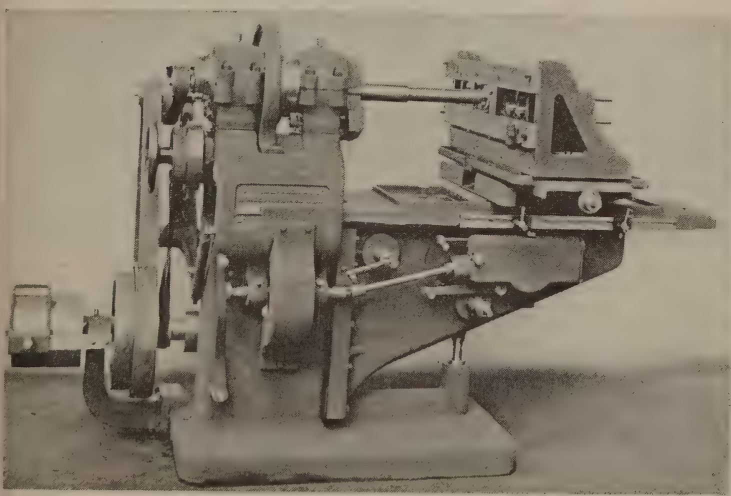

FIG. 271.—Cylinder grinding machine. (*Courtesy of The Heald Machine Company.*)

(within limits), straight or taper, may be finished in such parts as gears, bushings, cutters, gauges, etc.

In Fig. 271 is illustrated a machine for grinding straight holes in work of a shape or size that is inconvenient or impossible to rotate. The revolving-wheel spindle is carried in a revolving head, the revolutions of one being entirely independent of the other. This revolving head consists of two

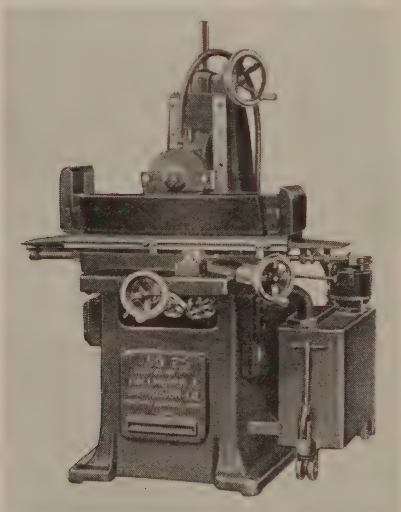

Fig. 272.—Hydraulically driven horizontal-spindle surface-grinding machine. Has stepless table speeds from 0 to 100 ft. per min., automatic feeds and cutting-lubricant system. (*Courtesy of Gallmeyer and Livingston Company.*)

eccentrics, one within the other with their relative positions adjustable, so that the *revolving wheel-spindle* may be arranged to travel in a circular path similarly as a crankpin travels. The diameter of this circular path is changed by means of a worm and wormwheel which permits of a slight adjustment for the purpose of feeding, or of considerable adjustment if desired for any reason. The worktable is provided with automatic feed in a direction parallel to the wheel spindle and with transverse adjustment. The knee which supports the worktable has vertical adjustment.

267. The Surface-grinding Machine.—This is a machine for grinding flat surfaces. There are two distinct types of surface-grinding machines, horizontal-spindle (Fig. 272), and vertical-spindle (Fig. 273). Surface-grinding machines are primarily for the purpose of finishing pieces that have been previously roughed on the shaper or milling machine, but high-duty vertical-spindle machines are manufactured that will efficiently finish flat surfaces of castings and drop forgings from the rough.

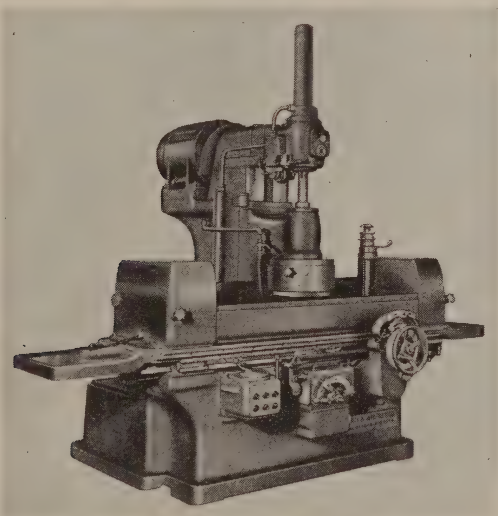

Fig. 273.—Hydraulically driven vertical-spindle surface-grinding machine. Has stepless table speeds from 0 to 100 ft. per min., automatic vertical feed of wheel from 0.00025 to 0.005 in., built-in wheel dresser and push-button control for all motors. (*Courtesy of Pratt & Whitney Company.*)

268. The Cutter and Tool-grinding Machine.—This machine is especially designed to sharpen reamers, taps, and all kinds of milling cutters. The machine illustrated in Fig. 274 has a fast and slow reciprocating movement of the table by either the handwheel or lever at the left. The handwheel at the right moves the wheel-head unit in and out from the table, and the vertical adjustment of the wheel spindle is made by the handwheel on top of the column. The convenient con-

trols and setting-up features of the machine itself, and the complete equipment of accessories, make it easy to set up and operate.

Most manufacturers of this type of machine publish a booklet illustrating and describing the methods of sharpening reamers and cutters in their machine.

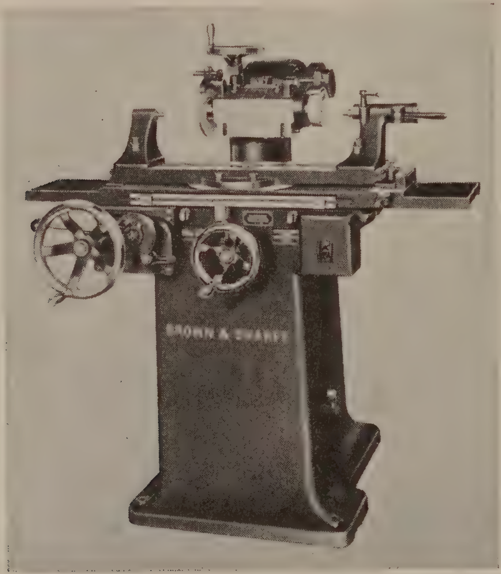

Fig. 274.—No. 10 Cutter and tool-grinding machine. Movement of table either by handwheel or hand lever is controlled by adjustable dogs. Swivel table permits angular settings. Wheel-spindle column has vertical adjustment and transverse movement. Universal head can be set at any angle to 90 deg., either side of center line, in both vertical and horizontal planes. Furnished with complete equipment of attachments. (*Courtesy of Brown & Sharpe Manufacturing Company.*)

269. The Universal Grinding Machine (Figs. 275 and 276). This machine is provided with a swivel table and also with a swivel headstock and a swivel wheel head. These features, in connection with certain attachments, permit of doing external and internal cylindrical grinding (straight or taper), surface grinding, face grinding, as on the sides of milling cutters, etc., and the backing off of reamers and cutters.

It is a valuable machine for general machine-shop and tool-room work.

270. Parts of the Universal Grinding Machine.—On the following pages is illustrated and described the Brown & Sharpe universal grinding machine. It differs from the plain machine in that it has certain special swiveling features and a number of attachments which permit of a greater variety of operations. While the following brief descriptions apply particularly to the machine shown in Fig. 275, they apply also in general principles to the basic elements of the plain grinding machine.

271. The Bed.—To avoid every possible chance of vibration, the grinding machine must be rigid. Accordingly the bed, which supports the table, the wheel stand, and the feeding mechanisms, is designed to give great strength and rigidity. The hearing surfaces (ways) for the sliding table are especially large (long and wide) and are very accurately machined and scraped. The rear top surface of the bed supports the wheel stand and is accurately machined, especially in relation to the table bearing surfaces in order that the center line of the wheel spindle shall be in exactly the same horizontal plane as the center line of the work. The bed is supported on a base of box form braced internally.

272. The sliding table is deep and strongly ribbed to retain its shape permanently. In operation this table slides back and forth on the bed and is consequently provided with bearing surfaces just as accurately made as the ways on the bed. To protect the ways extensions are provided on each end of the sliding table. A suitable portion of the top of the sliding table is machined to provide a seat for the swivel table.

273. The swivel table is pivoted on a large stud located in the center of the sliding table, and may be swiveled any amount up to 7 or 8 deg. in either direction from its normal position of parallel to the ways. This is for the purpose of grinding tapered work. Clamps are provided at both ends of the table. For the convenience of the operator when setting the table for a taper (or when setting it back to straight)

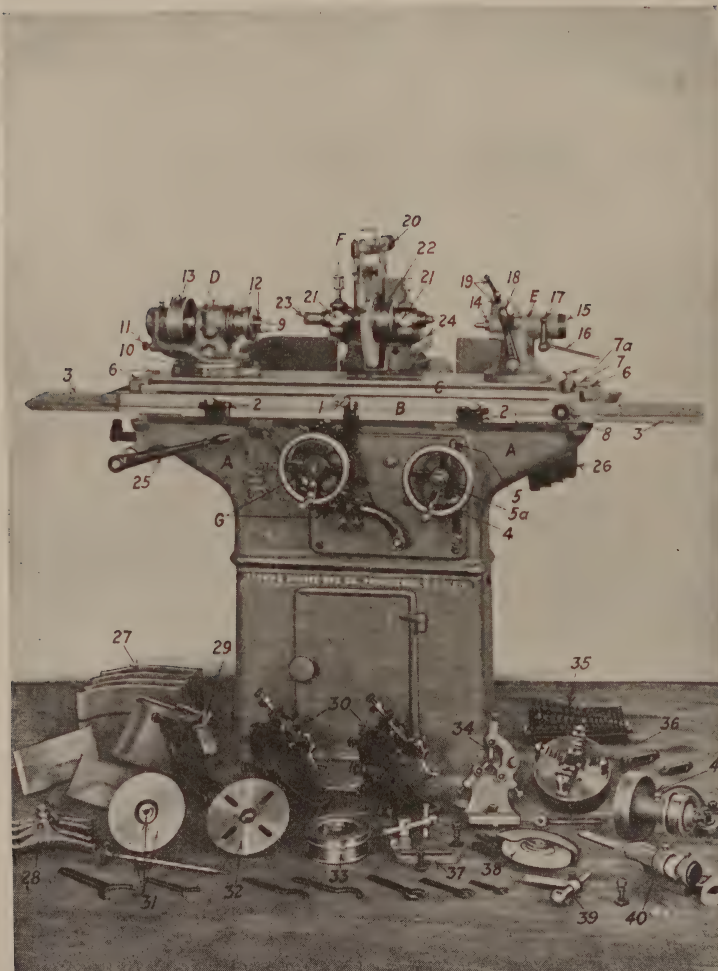

Fig. 275.—Brown & Sharpe universal grinding machine and accessories.

Parts of Grinding Machine

Unit Names

A. *Bed.*

B. *Sliding table.*

C. *Swivel table.*

D. *Headstock.*

E. *Tailstock.*

F. *Wheel head* (for detail see Fig. 279).

G. *Cross-feed controlling mechanism* (for detail see Fig. 282).

H. *Overhead works.* See Fig. 283.

Part Names

1. *Table-traverse reversing lever*, operates the mechanism which changes the direction of the movement of the table (either automatically by the reversing dogs (2) or by hand).

2. *Table-reversing dogs* operate the reversing lever and determine the length of stroke. These dogs may be clamped in any position in a rack on the table, and have provision for considerable adjustment after clamping.

3. *Bed guard* to keep water and dirt from the bearing surfaces.

4. *Handwheel* for table traverse.

5. *Control* for power feed of table. The control is sometimes a knob at 5*a*.

6. *Swivet-table clamping screws*, at both ends of table.

7. *Graduated scale for showing position of swivel table*, and 7*a*, *swivel-table locking pin.*

8. *Swivel-table adjusting knob.* First loosen clamping screws (6) and perhaps adjust locking pin 7*a*, then turn knob until the desired position of swivel table is indicated on graduated scale (7).

9. *Headstock center.*

10. *Headstock index pointer* indicates on graduated base the angular position of the headstock center with reference to the center line of the swivel plate.

11. *Live-spindle locking pin* for locking headstock spindle when grinding work on dead centers.

12. *Dead-center pulley* and *work driver* for driving work held on dead centers.

13. *Live-spindle driving pulley* for driving headstock spindle when using chuck.

14. *Tailstock spindle.* The tailstock spindle is backed up by spring tension to overcome any tendency of vibration of the work and to take care of the expansion in the length of the work which may be caused by the heat of grinding.

15. *Tailstock-spring guard.*

16. *Center with drawing-lever* for withdrawing the center when putting in or removing the work.

17. *Tailstock-spindle clamping lever.*

18. *Clamping lever* for clamping the tailstock to the table.

19. *Diamond-tool holder bracket* for clamping the diamond-tool holder (39) when truing the wheel. The diamond tool is clamped in the holder.

20. *Water piping.* The spout should be very close to the work and not over a quarter of an inch from the wheel.

21. *Grinding-wheel spindle boxes.*

22. *Wheel-driving pulley and sleeve.*

23. *Guard for end of spindle.* This end of the spindle is tapered, provided with a key and threaded to receive the offset wheel sleeve (38).

24. *Wheel stand* (see Fig. 279).

25. *Starting* and *stopping lever*, operates clutch in overhead works which permits of starting or stopping the work and automatic feeds without stopping the motor.

26. *Table-feed-mechanism cone pulley.*

Accessories

27. *Table splash guards.*

28. *Table splash-guard brackets.*

29. *Plain back rest.*

30. *Universal back rests.*

31. *Face chuck, chuck plate, and bushing*, also *face-chuck draw-in rod* for holding slotting cutters and similar pieces, when grinding to thickness.

32. *Face plate.*

33. *Large dead-center pulley.*

34. *Center rest.*

35. *Work dogs and dog tray.*

36. *Four-jaw chuck.*

37. *Tooth rest* used when sharpening cutters.

38. *Offset grinding wheel, wheel sleeve and wheel guard.*

39. *Diamond-tool holder.*

40. *Internal-grinding fixture.*

41. *Internal-grinding fixture countershaft.*

graduations are provided [(7), Fig. 275]. These graduations are for an *approximate* setting only. Never rely altogether on the swivel graduations when accuracy is desired. A T slot is provided in the swivel table for the purpose of bolting the headstock and the tailstock. Here again accuracy is not guaranteed; if the tailstock is moved, the exact setting for either straight or taper is changed.

274. The Table-feeding Mechanisms.—When the grinding machine is running and the control (5) (Fig. 275) is moved to

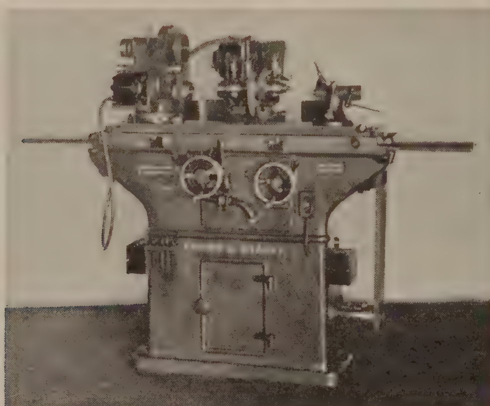

FIG. 276.—Motor-driven universal grinding machine. Practically the same as the belt-driven machine (Fig. 275) except that it is driven by individual motors, one mounted on the wheel stand, the second on the headstock, and the third at the rear of the machine for driving the worktable and the pump. (*Courtesy of Brown & Sharpe Manufacturing Company.*)

engage the clutch, the table starts to feed and will feed in the one direction until one of the dogs (2), pushes the table traverse reversing lever (1), which operates a bevel-gear reversing mechanism and changes the direction of the table feed.

The table-feeding mechanism and the reversing mechanism while fairly complicated for the beginner are ingenious and therefore interesting. The diagrams in Figs. 277 and 278 have been made merely to illustrate the principles of these mechanisms.

Motion is transmitted from the overhead works to the cone pulley (Fig. 277), thence through the reducing gears G_1, G_2, G_3 to the clutch shaft S_1 to which is feathered the sliding clutch-member C_1. The position of C_1 in gear G_4 or G_5 gives motion to and determines the direction of rotation of gear G_6 (bevel-gear reverse, see paragraph 177). Motion of G_6

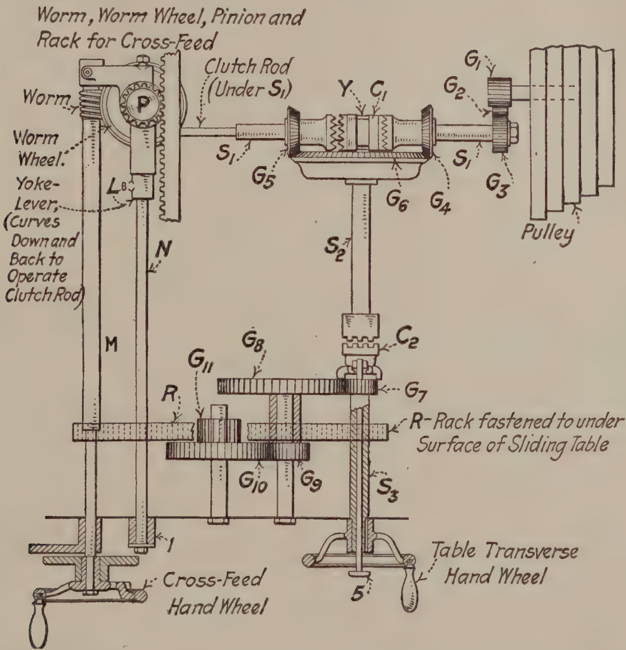

FIG. 277.—Table-feeding mechanism of grinding machine; also shows the worm, wormwheel, pinion, and rack for the cross-feed.

is transmitted through the shaft S_2 and (when the clutch C_2 is in) to the gear G_7 on the table-feed handwheel shaft S_3, thence through the quill gears G_8 and G_9 to the rack-pinion sleeve gear G_{10} and the rack pinion G_{11}. The pinion G_{11} meshes with the rack R which is fastened to the under surface of the sliding table. Of course, reversing the direction of gear G_6 reverses the direction of all the gears that follow, also the direction of the rack and consequently the table.

275. The Table-feed Reverse (Fig. 278).—The clutch member C_1 is moved to engage either gear G_4 or G_5 by the yoke Y which is fastened to the clutch rod R (for C_1, Y, G_4 and G_5, see also Fig. 277). The quick snappy action of the clutch rod (and yoke) necessary to throw the clutch C_1 instantly to reverse the direction of the table is due to the force of springs K_1 and K_2 (one for each direction). The increased compression and the release of the springs is obtained by means of a lever yoke L at the rear of the shaft N, Fig. 277, to which shaft is fastened the table traverse reversing lever (1). In fact the lever yoke L for compressing the springs is also fas-

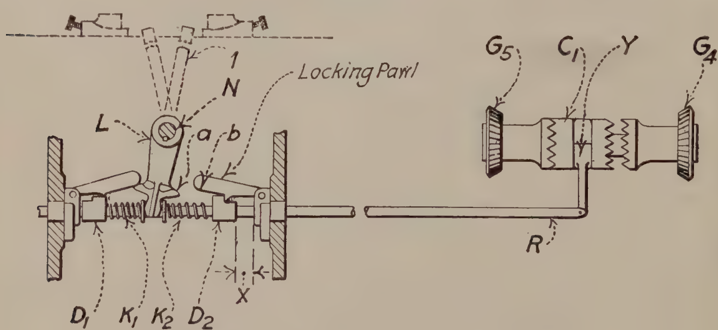

FIG. 278.—Table-feed reversing mechanism.

tened to the shaft N, as shown in Fig. 277, and curves down under the wormwheel to reach the clutch rod.

The dogs D_1 and D_2 (Fig. 278) are fastened to the clutch rod, and the springs K_1 and K_2 are coiled around the rod and are separated by the lever yoke L the end of which forms a yoke over the rod.

As shown in the sketch, the clutch member C_1 is engaged with gear G_5 and held by a locking pawl engaging D_2. As the reversing dog comes in contact with and pushes the reversing lever (1), the lever yoke L on the other end of the reversing shaft N moves to the right and compresses the spring K_2 until point a of the lever L lifts point b of the locking pawl and releases D_2. The force of the compressed spring thus released pushes D_2 and also the rod, the yoke, and conse-

quently the clutch which snaps into engagement with gear G_4 thus instantly reversing the direction of the table.

276. The Headstock.—It will be remembered that in lathe work if the live center runs out ever so little the cylindrical surface of the work turned will not be concentric with the centers. To obviate any chance of error of this kind the work to be ground on centers is revolved on two "dead centers," the headstock center as well as the tailstock center remaining stationary. The work is driven by a loose pulley, the bearing of which screws on the threaded nose of the spindle. The work-driving dog (35), Fig. 275, is driven by a pin which projects from the pulley. The spindle is held stationary by the stop pin (11).

When it is desired to hold work in the four-jaw chuck (36) or on the faceplate (32) or on the face chuck (31) the loose pulley is removed by unscrewing from the spindle, and the work holding device selected is screwed on the spindle. To revolve the work it will be necessary to arrange the suitable belt from the drum overhead to the spindle-driving pulley (13) and withdraw the stop pin (11) from the pulley.

The universal grinding machine headstock has swivel construction being pivoted on the base. Graduations in degrees indicate the position of the head. This swivel feature is useful for grinding angles and for face grinding, etc. (see Figs. 294 and 296).

The face chuck (31) as used in connection with its expansion bushing, tapered-head screw, and draw-in rod, is especially useful for grinding the sides of slotting cutters or any similar piece having a hole. The head is swiveled about 90 deg. and then adjusted carefully to give the slight concave surface (clearance) desired on the cutter or to exactly 90 deg. to give a flat surface on a disk or similar piece. A section view of the face chuck and a typical setup are shown on page 396.

277. The tailstock is clamped in the desired position on the table by means of a lever (18) and is aligned by the tongue which fits in the table T slot. Do not depend on this alignment for extreme accuracy. For example, if it is necessary

to change the position of the tailstock to accommodate shorter or longer work, the change may cause a slight error in the alignment of the centers.

The movement of the tailstock spindle to put in or remove the work is not obtained by means of a screw as in the lathe or milling machine. The adjustment of the work between centers is according to the force of a spring tending to push the tailstock spindle (and center) forward. The advantages of this construction are that the tendency of vibration is

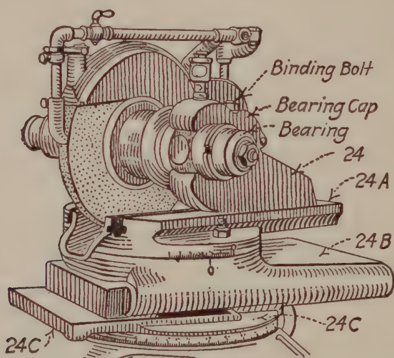

FIG. 279.—Grinding-machine wheel head. The *wheel stand* (24) may be clamped in the desired position on the *wheel-stand platen* (24*A*). The platen may be swivelled on the *wheel-stand slide* (24*B*). The wheel-stand slide bearings are very accurately scraped to fit similarly finished surfaces on the *wheel-stand slide bed* (24*C*), and the movement of the slide (24*B*) on the bed (24*C*) gives the cross-feed of the wheel. The bed is pivoted and may be swivelled and clamped in an angular position for the purpose of grinding abrupt tapers or angles. See Fig. 281.

largely overcome, and, as the work expands due to the heat generated in grinding, the center yields a sufficient amount. If the work is of such a size that its weight would tend to force the center back, the spindle may be clamped rigidly, otherwise it is not necessary.

A bracket (19) is provided for receiving and clamping the diamond-tool holder (39).

278. The Wheel Head (Fig. 279).—The relative positions of the parts of the wheel head (24 and 24*A*-*B*-*C*) determine the position of the wheel and the direction of the wheel feed.

The wheel is mounted between suitable flanges[1] on a hardened and ground spindle which runs in bronze bearings. The bearing boxes are inserted in bushings which fit in the arms of the wheel stand and are held in place by caps. When necessary to change the wheel, the wheel guard is removed, the caps which hold the bearings in place are loosened, and the wheel, spindle, and bearings are taken out and the change

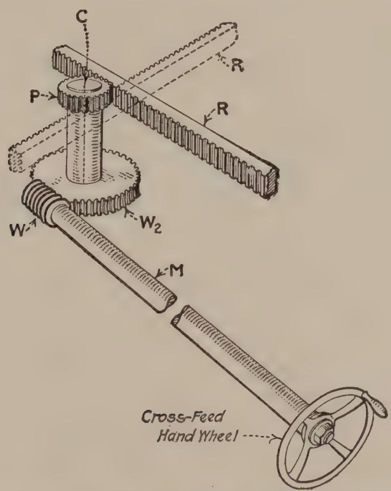

Fig. 280.—Sketch to illustrate the relative positions of the cross-feed handwheel, the shaft M, worm W, wormwheel, W_2 the pinion P, and the rack R which is fastened to the wheel-stand slide. Particular attention is called to the fact that the axis of the wormwheel and the pinion is in the pivot center of the wheel-stand slide, and consequently by turning the handwheel, the rack (and the wheel-stand slide) is moved (fed) no matter what its angular position on the bed may be.

of wheels made. When putting the wheel spindle and bearings back in the wheel stand, care must be taken to have all parts clean and the bearing bushings in the correct position, (oil hole up). Turn the wheel slowly by hand while first one cap and then the other is screwed down tight.

279. Cross-feed Mechanism.—The movement of the slide, 24*B*, Fig. 279, gives the cross-feed of the wheel. The feed mechanism is illustrated in Fig. 280. A movement of the

[1] For mounting grinding wheel see page 376.

cross-feed handwheel operates, through the shaft M, a worm W, and wormwheel W_2 to give motion to the pinion P which engages a rack R fastened to the wheel-stand slide. A plan view of the worm, wormwheel, pinion, and rack is shown in Fig. 277.

The wheel-stand-slide bed is so constructed that it may be swiveled for the purpose of grinding steep tapers and angles. The feed pinion for the slide is in the pivot center of the slide

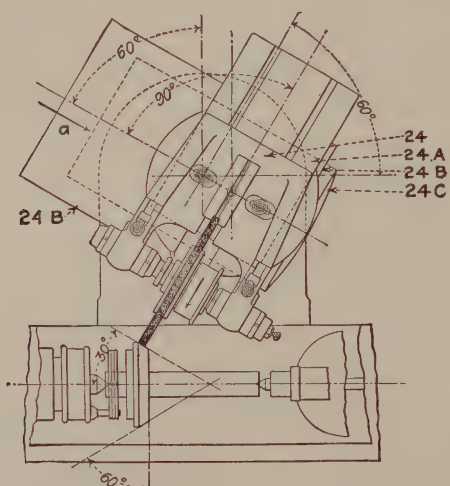

Fig. 281.—Grinding-machine wheel head set for grinding tapered work. Part numbers are same as shown in Fig. 279.

bed (C, Fig. 280), consequently when the cross-feed handwheel is turned, the wheel is fed along the work in the direction determined by the setting of the wheel-stand-slide bed.

In Fig. 281 is illustrated a typical setting for grinding at an angle. It will be observed that the wheel-stand bed 24C is swiveled 60 deg., carrying with it the wheel-stand slide 24B. This will cause the cross-feed to operate at an angle of 30 deg. with the center line of the work (arrow a shows direction of feed). In order to bring the face of the wheel parallel to the surface to be ground, the wheel-stand platen 24A, carrying the wheel stand 24, is swiveled 90 deg. on the slide. As the

cross-feed handwheel is turned, the wheel feeds across the angular surface of the work. To take a deeper cut, it is necessary to move the table-traverse handwheel a trifle.

The alignments of the wheel spindle and its supporting parts are such that no matter what cross-slide swiveling or sliding adjustments are made, the axis of the work will be in a horizontal plane in line with the headstock and tailstock centers. That is, no matter what shape or size of work is being ground, the cutting tool (wheel) is always "on center."

280. The Automatic Wheel-head Cross-feed.—Commercial grinding machines, internal, cylinder, plain, or universal are equipped with automatic cross-feed. Also for the purpose of greater efficiency, ingenious devices, automatically controlled, are provided by the different manufacturers for stopping the feed when the diameter of the work has been ground to the given size. It is, of course, necessary to adjust the cross-feed stop when setting the machine, and in the mechanically controlled mechanism it is necessary occasionally to make a further slight adjustment to compensate for the wear of the wheel. Following is a description of the cross-feed mechanism as applied to Brown and Sharpe grinding machines and the automatic stop which operates mechanically.

Brown and Sharpe Automatic Cross-feed (Fig. 282).—This consists of a ratchet wheel (6) fastened to a shaft (shown at *M*, Fig. 280) that controls the transverse movement of the grinding-wheel slide. A pawl (5), actuated through levers (3 and 4) by dogs (2) at both ends of the sliding-table traverse, operates the ratchet wheel and automatically draws the wheel slide in at each table reversal. The pawl continues to operate the ratchet wheel until a shield (10), fastened to an arm that revolves with the ratchet wheel, prevents it from further engaging the ratchet teeth. The cross-feed is therefore automatically thrown out when this point is reached. For any considerable movement of the shield lift the latch (8).

The ratchet wheel is graduated and each tooth is equal to a movement of the wheel slide of one eighth of a thousandth of an inch, or a reduction in diameter of the piece being ground

of one quarter of a thousandth of an inch. It is not necessary, however, to look at these graduations in setting the shield for light cuts so that any given number of thousandths will be

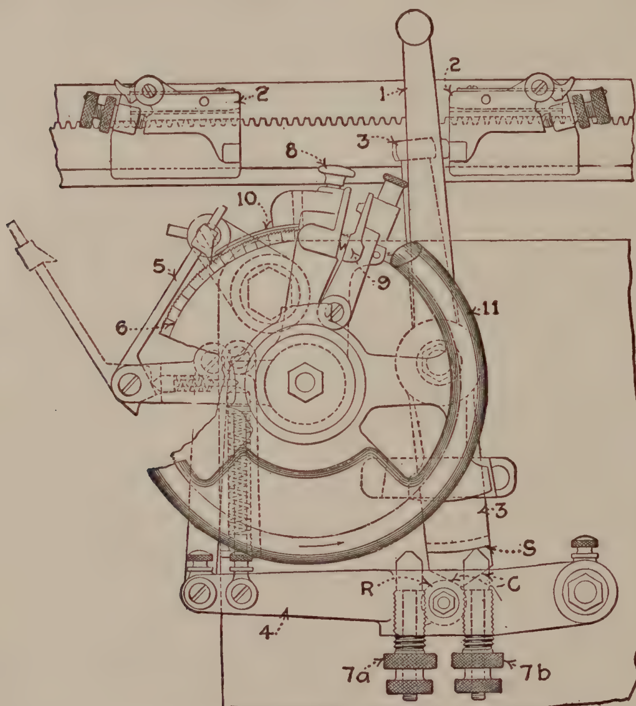

FIG. 282.—Cross-feed-controlling mechanism. 1. *Table-reversing lever.* 2. *Table-reversing dogs.* 3. *Auxiliary lever* is moved by the reversing dogs the same time the reversing lever is moved, and operates the feed lever. 4. *Feed lever* which operates the pawl. 5. *Pawl*—the amount of movement of the pawl on the ratchet wheel determines the amount of cross-feed. The distance the pawl moves is controlled by the positions of the adjusting screws. 6. *Ratchet wheel.* 7. *Adjusting screws.* 8. *Holding latch.* 9. *Changing latch.* 10. *Throw-out shield* for automatically stopping the feed. 11. *Handwheel.*

removed from the piece. The arrangement provided for this purpose, consists of a latchlike mechanism (9) that is pinched between the thumb and the forefinger, and each time it is pinched the shield (10) moves back one tooth on the ratchet wheel. So, if it is required to remove a given amount,

the grinding wheel is drawn in by means of the handwheel until it just trues up a place on the work. The diameter is carefully measured at this point and then, for example, if there are two thousandths more to come off, the latch is pinched four times for each thousandth to be removed, or eight times for the two thousandths; the machine will then grind exactly two thousandths from the piece.

Before a new piece of work is put in, the wheel slide is moved back by simply throwing the pawl out of engagement and turning the handwheel. After the new piece is carefully set in place and started revolving, the wheel slide is moved up until the wheel just touches the work, the pawl is thrown into action, and the table traverse started. When the pawl reaches the shield, the cross-feed will be thrown out and the piece will be the same diameter as the previous one. As the wheel wears, a slight adjustment of the slide can be made by means of the latch to compensate for the difference in the diameter of the work.

The feed operates only at the very ends of the table traverse, and the amount fed at either end is independent of that fed at the opposite end. For instance, 0.003 in. can be fed at each reversal on one end while 0.001 in. is fed at each reversal on the other end.

To Change the Amount of Cross-feed.—The greater the movement of the lever (4) in Fig. 282, the greater the feed, because the lever carries the pawl (5). The auxillary lever (3) operates at the reversal of the table and through the action of the cam (beveled surfaces C) on the roll R serves to move the lever (4) down against the force of a spring. The ends of the adjusting screws $7a$ and $7b$ bear in turn against the shouldered surface S on the lever (3) and act as stops against the upward (spring tension) movement of (4). The positions of $7a$ and $7b$ therefore determine the amount of feed at each reversal; the farther either screw is turned in, the less the feed at the corresponding reversal of the table.

281. The Overhead Works (Fig. 283).—The machine is started by moving the shipper S which moves the shipper rod

A and the fork *F* thus shifting the driving belt from the loose pulley (1) to the tight pulley (2). Motion is transmitted through the shaft (3) to the wheel driving cone pulley (4) to the second wheel driving cone pulley (5) to the wheel driving pulley (6) thence to the wheel sleeve and wheel. There are four steps on the pulleys (4 and 5), hence there are four wheel speeds available.

The movement (revolutions) of the work and also the feed movements (table traverse and automatic cross-feed) are con-

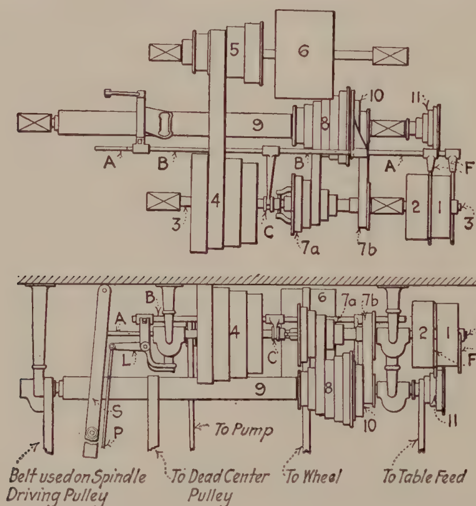

FIG. 283.—Overhead works. Views are looking from the top and from the front.

trolled independently of the wheel speeds. That is, the double-cone pulley (7*a*) and (7*b*) runs freely on the overhead works driving shaft (3) except when the clutch *C* is engaged. This clutch is controlled by the stop lever (25) in Fig. 275, working through a connecting rod *P* and a bell-crank lever *L* to the clutch-operating rod *B*. When the clutch is engaged, motion to the headstock (and work) is given through the cone pulleys (7*a*) and (8) and the "work drum" (9). There are six steps on the pulleys (7*a*) and (8); consequently there are six work speeds entirely independent of the wheel speed.

To operate the table traverse and the cross-feed mechanism, motion is given the cone pulley (26, in Fig. 275). This motion is transmitted from the cone (7*b*) to the cones (10) and (11), the latter two being fastened to a sleeve. There are five steps on the cone pulley (11) giving five speeds, and five more speeds are available by changing the belt to the other steps of the cone pulleys (7*b*) and (10), giving a total of ten table-traverse speeds (or table feeds).

It will be noted that by disengaging the clutch *C*, the work and also the table traverse are stopped without stopping the wheel. This serves the double purpose of saving time and keeping the wheel bearings at a uniform temperature. The latter is necessary in accurate grinding. It may be said that after a wheel has been running a few minutes, it sort of adjusts itself. In other words, a wheel in cold bearings will not "size" the work the same as if the bearings are warm.

Questions on Universal-grinding-machine Construction

1. Move the sliding table by hand. How does turning the handwheel serve to move the table?

2. What similarity of construction do you notice in the mechanism for moving, by hand, the table of the grinding machine and the carriage of the lathe?

3. In the power drive for the table there are several pairs of "reducing gears." What is the object of having one of the gears in each pair smaller than the other?

4. Compare the power drive of the grinding-machine table to the drive of the planer platen. In what respects are they similar?

5. What mechanism is used to reverse the movement of the grinding-machine table?

6. How does turning a handwheel serve to operate the cross-feed of the grinding wheel?

7. Explain why the cross-feed pinion is in the swivel center of the wheel-stand-slide bed.

8. How does the cross-feed mechanism in the grinding machine differ from the cross-feed mechanism in a lathe?

9. Why not have the cross-feed in a universal grinding machine operate by a screw?

10. Why is it possible to do *more* work in a machine having automatic feed?

11. Why does automatic feed make for *better* work?

12. Do you know how to make the adjustment to feed the desired amount at each end of stroke?

13. How is the automatic feed stop set?

14. There are two pulleys on the headstock, one keyed to the spindle the other running freely. Explain the purpose of these pulleys.

15. What is the purpose of the stop pin in the headstock?

16. Why is the headstock made so it can be swiveled?

17. What is the reason for the spring in the tailstock?

18. How is the diamond held when truing the wheel?

19. How is the tailstock moved on the table? Is perfect alignment maintained if the tailstock is moved?

20. How is the grinding-machine table swiveled?

21. How many wheel speeds has the machine you are studying?

22. How many work speeds has this machine?

23. Explain how you are able to stop the work without stopping the wheel. Why is this an advantage?

24. What is the purpose of the long pulley (work drum) in the overhead works?

25. Sometimes the belt from the drum to the headstock is unduly stretched. How does this happen?

26. What is a *plain* grinding machine? A *universal* grinding machine?

27. Are there any other grinding machines in the shop? If so, what are they called to differentiate them?

28. State at least three reasons why the grinding machine is an indispensable tool.

CHAPTER XV

GRINDING WHEELS

282. Introduction.—Success in grinding depends more upon the knowledge the operator has of the characteristics (and particularly the action under different conditions) of the grinding wheel, than upon anything else. It is an interesting study, and the more deeply one gets into it the more interesting it becomes. Grinding offers to the young machinist one of the most fascinating and worth-while studies in the whole field of machine work.

Take any grinding wheel and examine it, preferably with a magnifying glass if one is at hand. It will be observed that the wheel is made up of a great many particles of abrasive bonded together. There are various materials used to hold the crystals of abrasive together. They are called *bonds*. Some wheels are much coarser than others; the size of the particles of abrasive determines the coarseness or fineness of the wheel, similarly as the size of the teeth determine the coarseness or fineness of a file.

It will be observed further that the particles of abrasive have sharp projecting edges and points (crystalline fracture). These are the cutting edges, and the abrasive is hard enough to cut hardened steel and tough enough to stand up and not fracture under the cutting pressure. The action of the abrasive or grinding wheel, mounted on the spindle of the grinding machine, and revolving at a high rate of speed, is to bring a countless number of cutting points and edges in contact with the metal to be removed. An abrasive wheel is a *cutting tool.*

The little cutting points and edges become dull after a time and to "keep the wheel sharp" it is necessary that the dull

particles be removed to allow the sharp particles underneath to appear and do the cutting. The ideal wheel would have a bond just strong enough to permit the wheel automatically to sharpen itself, that is, when the cutting edges were too dull to do good work on the given material, the excessive pressure of the cut would serve to break away the dull particles. The different grinding jobs offer variable conditions of cutting pressure, etc., and consequently the particles of abrasive are more firmly held together in some wheels than in others. The wheel which retains its particles with the greatest tenacity is called *hard,* and the wheel from which the particles are easily removed is called *soft.* (Remember the particles are no softer in a soft wheel, but the *bond* is less strong, which makes the *wheel* softer.)

The tendency of most machinists is to use a wheel that is too hard. "Use a soft wheel" is almost as important a slogan in grinding as "keep cutters sharp" is in milling. To be sure a soft wheel does wear away more rapidly, but is it not wiser to wear out a $3 wheel earning $100 than to save part of the wheel and earn only $50 in the same length of time?

Before proceeding to a discussion of their selection and use, brief descriptions of the distinguishing features of grinding wheels are offered. These few pages will give an idea of what grinding wheels are, of the differences in materials and methods that obtain in making wheels for various purposes and of the care that must go into the making. The features of any grinding wheel are:

1. The *manufacturer,* that is, the facts concerning the uniformity and reliability of the product, and the kind of service rendered by the company.
2. The *abrasive,* probably under a trade name.
3. The *grain,* meaning the size of the particles of abrasive.
4. The *kind* of wheel, that is, the process of manufacture, which is according to the kind of *bond* used to hold the particles of abrasive together.
5. The *grade*—"hardness" or "softness" of the *wheel,* not of the abrasive.

6. The *structure*, controlled in the given grade and grain of wheel by the spacing of the particles of abrasive to obtain a greater or lesser density.

7. The *classification* or *grading*. The manufacturer's classification of the characteristics of the wheel. This is usually furnished on a ticket with the wheel and should be preserved for use when reordering.

8. The *types* (shapes). There are nine standard shapes (see Fig. 284) and several special shapes.

9. The *dimensions* (see Fig. 284).

283. The Manufacturer of Grinding Wheels.—There are several well-known makers of grinding wheels and other abrasive materials, each having special manufacturing methods, and usually a trade name for the product. These companies are glad to send, free of charge to those who write for them, booklets that give information on the selection, use, and care of their products. This information is both general and special, authoritative and comprehensive, especially interesting in the way it is presented, and well worth while in view of the great importance of grinding in industry.

284. Abrasives.—An abrasive is an extremely hard, and more or less tough substance, which when fractured, has the formation of many sharp cutting edges and corners. Some of the abrasives used in shop practice, such as sandstone, emery, and corundum, are natural products, while others, such as carborundum, alundum, crystolon, and aloxite, are artificial products.

Abrasives are used in machine shops in many ways: in loose grains for polishing, also for lapping; in many shapes and sizes of "sticks" and oilstones for final fitting jobs in hardened parts, as well as for sharpening tools; glued to cloth and paper in sheets, disks, or long strips (emery cloth and sand paper) for grinding and polishing; and in hundreds of shapes and sizes of grinding wheels.

285. Natural Abrasives.—The old-fashioned "grindstone" is an abrasive wheel made of *sandstone*, which is a rock consisting of sand, more or less firmly united by some cement such

as silica, iron oxide, or calcium carbonate. Sandstone being comparatively softer than the more modern abrasives, the grindstone has been almost entirely superseded by the more efficient grinding wheels.

Emery is a natural product consisting of from 50 to 60 per cent crystalline aluminum oxide[1] which gives it the valuable properties of hardness and toughness essential to an abrasive. The other principal substance in emery is iron oxide, which gives it the dark color.

Corundum is similar to emery, but has a much larger percentage (about 75 to 90 per cent) of crystalline aluminum oxide. It is, therefore, harder than emery and somewhat lighter in color. The best corundum is found in Canada.

286. Artificial Abrasives.—Methods have been developed for producing artificial abrasives that are superior in many ways, especially in uniformity of quality, to the natural abrasives. They are products of the hydroelectric furnace and are mostly manufactured in the vicinity of Niagara Falls where electric power is cheap. The first produced was silicon carbide (1893) and then aluminum oxide (1897). They are manufactured in great quantities, and marketed under various trade names.

Following are some of the familiar trade names:

Manufacturer	Silicon carbide	Aluminum oxide
Abrasive Company	Electrolon	Borolon
Carborundum Company	Carborundum	Aloxite
Macklin Company	Ironite	Stellite
Norton Company	Crystolon	Alundum
Precision Grinding Wheel Company	Lotens	Hytens
Safety Emery Wheel Company	Corex	Rex
Sterling Grinding Wheel Company	Sterbon	Sterlith
Vitrified Wheel Company	Carborite	Borite
Waltham Grinding Wheel Company	Carbowalt	Alowalt

[1] Aluminum oxide (alumina) forms the basis of many rocks and soils. In its uncrystallized form it is a soft white powder, when crystallized

The tendency is to get away from these trade names and specify merely *silicon carbide* or *aluminum oxide.*

287. Silicon carbide is the crystalline formation of two elements, silicon and carbon, accomplished by subjecting a mass of silica sand and coke (with relatively small amounts of sawdust and salt for certain chemical reactions) to a heat of about 4,000 deg. F. for 30 hr. or more in a resistance-type electric furnace. The modern furnace is about 6 or 8 ft. wide and high, and about 40 ft. long. The crystals formed by this process, tons at a time, are extremely hard and sharp, but quite brittle. When cooled, the masses of beautifully colored crystals are crushed and recrushed under great rolls, cleaned of all impurities, and screened for various sizes.

Owing to the extreme brittleness of crystals of silicon carbide, the grinding wheels made of this abrasive are not best adapted to grinding materials of high tensile strength, such as steel, but are recommended for materials of lower tensile strength, such as cast iron, brass, bronze, aluminum, and copper, also nonmetallic substances such as rubber, celluloid, marble, and glass.

288. Aluminum oxide is produced in an arc-type electric furnace by charging bauxite, a clay, which contains the purest form of aluminum oxide found in commercial quantities, with given percentages of ground coke and iron borings. In the huge arc furnace the chemically combined water is driven off, impurities in the ore are reduced to their metals, combine with the iron, and collect at the bottom, and heavy masses ("pigs") of crystalline aluminum oxide, one of the hardest materials known, are formed. The pigs are crushed, the impurities separated, and the grains screened in standard sizes.

Crystals of aluminum oxide are very hard and sharp, and, in addition, the "temper," that is, the combination of hard-

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it is one of the hardest substances known. Some of the most valuable of the precious stones, for example, the ruby and emerald, are nearly pure crystallized alumina. Emery and corundum may be compared to a crystallized sponge with the intersticies filled with impurities. They are hard in proportion to their content of crystallized aluminum oxide.

ness, toughness, and fracture, can be controlled in manufacture to suit the conditions for which the abrasive is to be used. They are not as hard as crystals of silicon carbide, but are less brittle and will stand up better when grinding materials of high tensile strength, such as carbon and alloy steels—soft or hard—malleable and wrought iron, tough bronzes, etc.

289. Grain.—After the abrasive material is crushed, and cleaned of the dirt and other impurities, it is sorted into sizes by passing through series of vibrating silk screens having meshes ranging from 6 to 240 per *linear* inch. By the term *grain* is meant the size of the particles of abrasive, according to the hole size of the finest screen through which they will pass, as, for example, 36-grain, 60-grain, or 240-grain. Finer grains, 1F, 2F, and 3F are classified by water flotation according to the time taken to settle.

Two or more sizes of abrasive are often combined to impart to a wheel practically the advantages of the coarser grains for deeper cutting, and the finer grains for smoother finish. Such a wheel is known as a *combination wheel.* The first number on the wheel identification tag denotes the grit or grain size and also the combination, if any. For example, 144 means, in one make of wheel, No. 14 grit and No. 4 combination. Each company has its own method of marking, and also its own carefully guarded formulas.

290. Bonds.—The bonds used in the manufacture of abrasive wheels are the materials which, when fused, baked, or otherwise matured, serve to hold (bind) the grains of abrasive more or less firmly together. The great majority of grinding wheels are *vitrified* wheels, in which the bond is a mixture of ceramic clays, which, when fused (vitrified) becomes a kind of glass or porcelain.

Silicate of soda is used in a semivitrified process to make the so-called *silicate* wheels. Various organic substances such as rubber and shellac are used for the thinner, more elastic wheels, and, more recently, *resinoid* wheels (synthetic resin as a bond) have been rapidly developed as being particularly

valuable for work requiring thin wheels and other very strong wheels.

The general characteristics of the bond—vitrified, silicate, or organic—determine the *kind* of wheel, and the way in which the given bond is used, quantity ratio and treatment, determines the *grade* of the wheel, that is, the tenacity with which the abrasive particles are held.

291. Vitrified Wheels.—A large proportion of grinding wheels are made by the vitrified process. Suitable ceramic clays are mixed with the abrasive in exact proportions, enough water is added to give the desired consistency, and the whole stirred in power-driven kettles. The mixture is then formed into oversize shapes either (1) in settling molds, or (2) under hydraulic pressure. When sufficiently dry, the "wheels" are "shaved" to approximately the shape and size required. They are then taken to the kilns, where they are very carefully set to avoid distortion during the burning, and subjected to a controlled temperature for 100 hours or more. The heat is gradually increased until the clay vitrifies (fuses), and a week or more is allowed for the gradual cooling. As the vitrified clay cools, it crystallizes and binds the grains of abrasive firmly together.

The vitrified wheel has certain advantages: (1) It is porous; the chips have room to free themselves, which makes the wheel *free cutting*, that is, it does not quickly clog up with particles of the material being ground. (2) The process of manufacture makes for uniformity in the grade of the wheel; it does not contain "soft spots." (3) It is unaffected by water, acids, oils, heat, or cold. It has, however, certain disadvantages: (1) The process of making is slow; special orders cannot be quickly filled. (2) It is impracticable to make vitrified wheels over 36 in. in diameter. (3) Vitrified wheels have no elasticity, and thin wheels break so easily as to be impractical.

292. Silicate Wheels.—Silicate or semivitrified wheels are made with silicate of soda as a bond. After the abrasive and bond are thoroughly mixed, the wheel shapes are molded and then baked. A much lower heat for a much shorter time than

in the case of the vitrified wheels causes a chemical reaction which sets and hardens the bond. Wheels up to 60 in. in diameter can be made by this process.

Silicate wheels are not as free cutting and therefore not as fast cutting as vitrified wheels, but they cut smoothly and coolly and are used, in machine shops, in wet tool grinders, and for surface grinding with cup and ring wheels having a large area of contact with the work.

293. Rubber- and Shellac-bonded Wheels.—These are classified as *elastic* wheels. They have certain advantages but are not efficient except in operations where the use of other kinds is impracticable. Their advantages may be listed as follows: (1) They have great tensile strength, and even when very thin, they are safe and efficient. (Rubber wheels are made as thin as 0.005 in. for slotting pen points.) (2) They are smooth cutting, giving a beautiful finish, wet or dry. (3) Owing to their elasticity, fairly deep side cuts may be taken. (4) Being a very compact wheel, and elastic, they keep their shape well, even in the corner cuts, such as saw gumming. (5) The elastic bond allows a wide selection of grains and grades. (6) They are especially efficient for grinding brass.

294. Resinoid-bonded Wheels.—The material of this bond is well known under the trade names of "Bakelite," "Redmanol," etc. It is of increasing importance as a bond for the reason that it produces a wheel that is very strong, comparatively free-cutting and fast-cutting. The finish is about equal to that of vitrified wheels. Very thin resinoid-bonded cutoff wheels, 16 in. in diameter, ⅛ in. thick, for example, may be run at 15,000 surface feet per min. (nearly 3 miles per min.) and heavy wheels for snagging castings at 9,000 s.f.p.m.

295. Grade.—In grinding practice grade means the strength of the resistance that the given grain and bond combination offers to the grinding forces that tend to tear away the particles of abrasive from the surface of the wheel.

Wheels from which the abrasive is more readily broken away are known as *soft* grade, and those that strongly retain the

particles are called *hard* grade. The degree of hardness or softness can be controlled in manufacture and is designated by letters or numbers. (Table 11, page 488), shows how necessary it is for the purchaser to designate the maker's name as well as the grade, size, shape, etc.

296. Structure.—In an abrasive wheel this term refers to the grain spacing, that is, the density. The kind of bond used has, of course, its effect upon the structure of the wheel, but, also, varying densities of wheels having the same abrasive and the same bond are made and the degree of density exactly controlled in manufacture. For example, if amounts of abrasive and bond mixture, say 17 oz. and 16 oz., respectively, for two wheels, are compressed into the same volume, the heavier wheel will have the closer structure.

It has been found in many cases that wheels of a certain density, say, of an open structure, will cut a given material more freely and faster, and will last longer, than a wheel of the same grade and grain but of a closer structure. The manufacturers are able to recommend the structure, as well as the grade and grain, most likely to be best suited for the job, and, of course, the intelligent machinist or job foreman must be able to check these recommendations.

297. Grading or Classification.—The term "grade" has been defined as the strength of the wheel in holding its particles. *Grading* must not be confused with grade. Grading a wheel denotes a knowledge, on the part of the maker, of the sum total of the wheel's characteristics. It will be understood that there are hundreds of combinations of grain sizes, bond mixtures, and process treatments. For example, more bond and less abrasive in a given wheel would result in a different *structure*. Or a given bond with a coarser grain size gives a wheel that *acts* softer than the same bond and treatment with a finer grain. Also, different degrees of hydraulic pressure in forming the wheel have varying effects.

Through years of obtaining experimental and commercial production records, the wheel manufacturers have been able to classify and catalogue the characteristics of the best wheels to

use for hundreds of operations, under varying conditions of machines and materials. The letters and figures that denote the characteristics (the grading) of a certain wheel may be furnished with the wheel, but they mean very little to the operator except for reorders. For example, a resinoid wheel made by The Carborundum Company is catalogued as 144-11-K11VX-32B. The number 144 denotes the grain combination; 11 is the grade; K11VX is the bond—proportion of elements, treatment, etc.; and 32B indicates a certain density, the *structure*.

It is not really as complicated as it sounds. If such a wheel seems to cut satisfactorily, it may be reordered; if it is not quite satisfactory, the expert can usually tell where a slight change in either grain or bond or structure will benefit.

The secrets of the combinations indicated by the letters and figures are the property of the manufacturer.

298. Shapes and Sizes of Grinding Wheels.—For purposes of simplification, wheels of certain types (shapes) and dimensions have been adopted as standard in the United States and Canada. It is thought that ultimately many of the special shapes will be eliminated. The nine standard types are numbered (Fig. 284) and each dimension designated by letter. The key to the dimensions[1] is shown with Fig. 284.

To give an idea of the great number of sizes of standard wheels, the straight wheel, Type No. 1 may be selected. These wheels are stocked, in vitrified bond, in over 250 sizes, from ¼ in. in diameter and ¼ in. thick to 24 in. in diameter and 8 in. thick, or 36 in. in diameter and 4 in. thick; in organic bond, in one table, 136 sizes, in diameters from 1 to 30 in., and thicknesses ⅛ to 4 in. In another table 22 sizes of cutting-off and slotting wheels (also Type No. 1) are listed, ranging from 4 in. in diameter and 1/32 in. thick to 16 in. in diameter and ⅛ in. thick.

[1] If interested in the tables of sizes, etc., the reader is referred to the booklet, "Grinding Wheels, Simplified Practice Recommendations," for sale by the Superintendent of Documents, Washington, D. C. (Price 5 cents.)

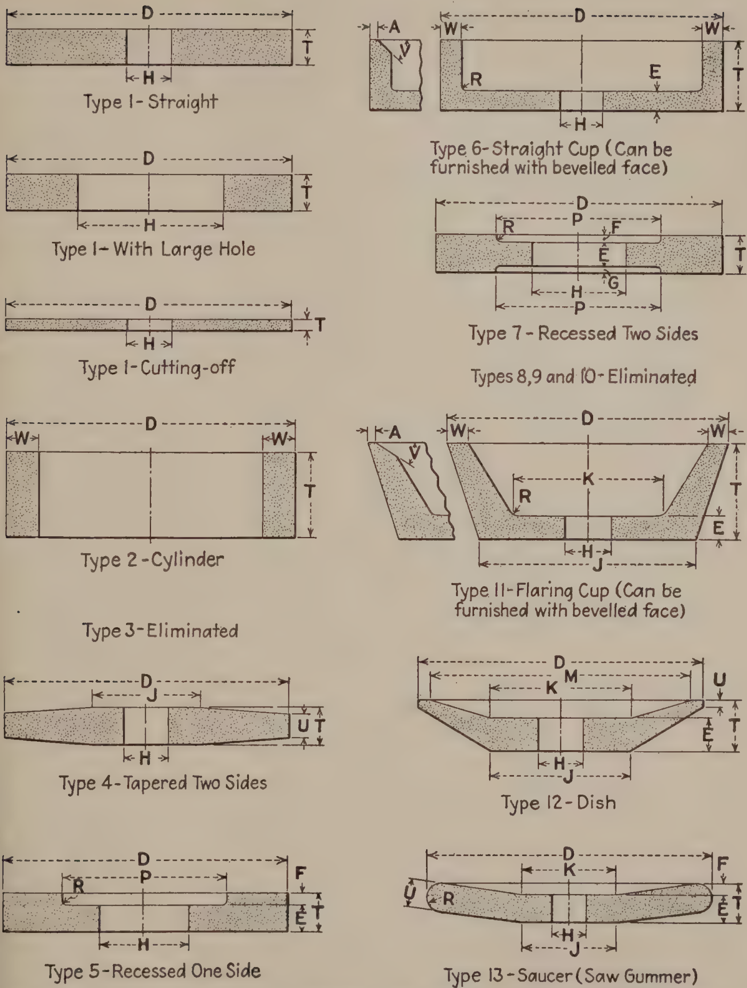


FIG. 284.—Types (shapes) of grinding wheels. Types 3, 8, 9, and 10 are no longer stocked as standard.

Key to letter dimensions:

A, flat spot of beveled wall
D, diameter (over all)
E, center or back thickness
F, depth of recess (see type 5)
G, depth of recess (see types 5 and 7)
H, arbor hole
J, diameter of flat or small diameter
K, diameter of flat inside
M, large diameter of bevel
P, diameter of recess
R, radius
T, thickness (over all)
U, width of face
V, angle of bevel
W, thickness of wall

It has been the practice in the past, and continues to be to a considerable extent, to give, when ordering, the name of the machine and the number of the wheel for the given purpose. For example, Brown & Sharpe No. 15 is a straight wheel 10 in. in diameter and ½ in. thick, with a 3-in. hole. There are 58 different numbers in the Brown & Sharpe list.

The standard face shapes of straight-type wheels are denoted by capital letters as shown in Fig. 285.

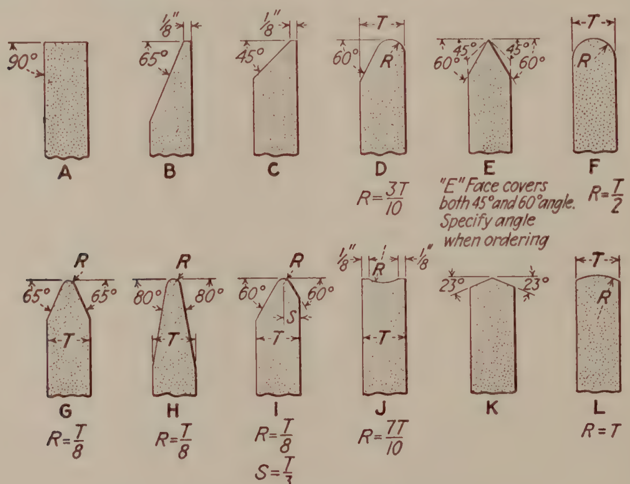


Fig. 285.—Shapes of grinding-wheel faces.

It is not, of course, necessary to be familiar with more than a comparatively few types and gradings of wheels, but it is interesting to get another view of the great importance of the grinding machine in industry.

299. Final Operations in Making the Wheel.—These may be listed in order as follows: truing, bushing, checking the grade, balancing, speed testing, and inspecting.

Truing.—From the kilns the wheels go to the truing lathes where they are very rapidly trued to shape and dimensions. Special wheels, say for grinding crankshafts, are accurate in thickness to within two or three thousandths of an inch. The diameters are turned after bushing.

Bushing the Wheel.—The arbor holes of most grinding wheels are bushed with lead or babbitt. Care is taken to have the hole true, and to trim the bush flush with the sides.

Checking the Grade.—This is commonly done by hand, by slightly twisting a short screwdriver-like tool into the side of the wheel. The resistance offered, compared with the resistance of the bond in a wheel of known grade, indicates the grade.

Balancing.—Any rapidly revolving element in a machine should be "balanced"; that is, no half of its weight about its axis should be heavier than the opposite half. Machine parts such as pulleys, flywheels, driving wheels, etc., must often be balanced even after turning. Balancing is accomplished by adding weight to the light side or taking weight from the heavy side.

A revolving part out of balance absorbs more power, causes greater wear in the bearings, sets up undue vibrations and, in the larger pieces especially, is more likely to break. It will be readily understood then how important it is that grinding wheels shall be in practically perfect balance.

Wheels over 12 in. in diameter are tested for balance. If one is found out of balance the amount is noted in ounces, a cavity is made near the hole on the light side and filled with enough lead to balance. In the larger sizes, as the wheel wears, an out-of-balance condition may develop that will defeat good work and may prove a positive danger. Therefore the larger wheels should be tested occasionally and if necessary corrected.

In grinding machines using large wheels provision is often made for balancing by having a suitable weight, on one of the wheel flanges, that may be shifted as desired. Also certain wheel makers provide a lead bushing, a part of which may be removed to balance the wheel.

Speed Testing.—Wheels 6 in. in diameter and larger are given a speed test. They are run, under a hood, at a rate of at least one and a half times the recommended speed. This gives a stress of more than double that which is given in actual practice.

Inspection.—Grinding wheels are rigidly inspected to guard against errors in shape, size, grain, and grade, and any imperfections such as cracks, chipped places, and blowholes.

300. Diamond Wheels.—Before leaving the chapter on grinding wheels, a word may be said about diamond wheels. For many years a certain amount of very accurate grinding has been done with small steel disks having the periphery impregnated with diamond dust. These little wheels, when used for internal work, were often called "diamond laps."

Since the advent of cemented carbide,[1] and the resulting need of abrasive wheels suitable for sharpening the carbide lathe tools, milling cutters, etc., the commercial diamond wheels, in straight-, cup-, and dish-wheel shapes, and special wheels for form grinding, have been developed. The diamonds used in making these wheels are South African borts (see page 378). They are crushed under heavy rolls of very hard material, such as manganese steel, and then screened to get the standard grain sizes, 100, 180, 200, 240, 320, and 400. Mixtures of diamonds and bond are made in different *diamond concentrations*, that is, with varying proportions of diamonds per volume of mixture. The given mixture is coated on the working surface only of the wheel shape, which is of special composition material. The coating is applied in regular thicknesses of $\frac{1}{32}$, $\frac{1}{16}$, or $\frac{1}{8}$ in., as ordered.

Naturally these diamond wheels are expensive as to first cost, but carbide tools can be reconditioned in a fraction of the time required with other abrasive wheels, and a sharp, smooth edge is obtained without hand lapping. The price is according to (1) the size of the wheel, (2) the diamond concentration, *A*, *B* or *C* (*C* having four times as many carats as *A* per unit volume of coating), and (3) the thickness of the coating. Of course, the wheel with a $\frac{1}{8}$-in. coat will last four times as long as the wheel with a $\frac{1}{32}$-in. coat, but it seems to be true, with respect to the concentration, that a higher degree of finish and longer wheel life are obtained with the

[1] For description of cemented carbide, see Part I, page 92.

use of the *lower* diamond concentration, and at only a slight loss in production.

Extreme care must be taken in mounting the diamond wheel. It should run at about 5,000 s.f.p.m.—never more than 6,000. It is best to use *plenty* of coolant—water or soda water, or a grinding solution. The proper dressing of the wheel requires understanding of why and how, and the art of grinding the carbide tools involves knowledge, skill, and care to avoid waste of the wheel and tool. What is stated here is meant only as an introduction; the care and use of the diamond wheel, and the grinding of carbide tools is fully illustrated and described in booklets published and sent free by the manufacturers of the wheels; for example: The Carborundum Company, Niagara Falls, New York; and the Norton Company, Worcester, Massachusetts.

Questions on Grinding Wheels

1. Examine an abrasive wheel. What shape is it? What diameter is it? How wide is the face? What size hole has it?

2. Is the wheel you are examining hard, medium, or soft? Is it coarse or fine? Is it sharp? Is it glazed?

3. Emery cloth, sand paper, oilstones and grinding wheels are made of abrasives. What is an abrasive?

4. Why does an abrasive *cut?*

5. State two reasons for the use of artificial abrasives.

6. Some grinding wheels may be easily scratched with a knife or a file, while others are hard to scratch. How do you explain this?

7. What is the definition of the word "vitrify?"

8. How are wheels classified as to *grain?*

9. Is the classification of wheels fairly uniform among the various manufacturers? Give reason.

10. How are wheels classified as to *grade?* Is this classification standardized?

11. If you were ever required to write an order for grinding wheels, what information as to sizes, etc., would you furnish the dealer?

12. What is the purpose of the soft washers used in mounting a grinding wheel?

13. State three facts concerning the flanges between which the wheel is mounted.

14. What are some of the reasons for balancing a wheel?

15. Give four suggestions concerning the use of the diamond.

CHAPTER XVI

GRINDING PRINCIPLES AND PRACTICE[1]

301. Introduction.—Grinding is the process of removing metal by means of an abrasive wheel. The results which may easily be obtained, with the proper wheel in a well-made machine intelligently operated, are extreme accuracy, a fine finish and rapid production. The work may be of any size or shape within the capacity of the machine and of practically any of the materials, hard or soft, used in machine construction. The grinding machine is the standard machine tool for the accurate sizing of hardened pieces.

The grinding machine is primarily for finishing surfaces that have previously been roughed out in another machine, hence its value lies not in the amount of metal removed in a given time but in the accuracy of its product and in the ease by which this accuracy may be obtained. That is, cylindrical or tapered pieces may often be finished in a grinding machine quicker, better, and cheaper than they could be turned to exact size; holes in many of the parts made of the tough alloy steels or even of cast iron may be ground easier and quicker than they can be bored to size or reamed; and many flat surfaces may be finished and accurately sized in the surface-grinding machine, especially with the use of the magnetic vise, more efficiently than in any other machine. A surface properly ground is beautifully smooth and free from feed marks, scratches, or chatter marks.

In this chapter certain definitions are given, and the factors of wheel speeds, work speeds, arc of contact, etc., as they enter into the successful practice of grinding, are described. The selection, mounting and truing of the wheel, and the setup of the job are discussed in detail.

[1] The photographs for the half-tones in this chapter are furnished through the Courtesy of the Brown & Sharpe Manufacturing Company.

302. Kinds of Grinding.—By *cylindrical grinding* is meant the grinding of outside cylindrical surfaces; most grinding is cylindrical. External tapers and angles may be ground, and the same principles of wheel action, work speeds, wheel speeds, etc., apply as in cylindrical grinding. By *internal grinding* is meant the grinding of holes either straight or taper. By *surface grinding* is meant the grinding of horizontal flat surfaces. When the flat surface being ground is vertical, the operation is called *face grinding.* In face grinding the face (periphery) of the wheel may be used as when grinding the side of a revolving disk (see Fig. 296), or the side of the wheel may be used if it is under cut a trifle (see Figs. 295 and 303), or a cup wheel may be used.

When grinding cylindrical, taper, or angular pieces, whether external or internal, several chips are usually taken by the *traverse method* of grinding. That is, the automatic cross-feed for the wheel is set to operate a definite infeed for each pass, and the longitudinal feed (traverse) is set for a certain amount each revolution of the work.

Frequently when grinding comparatively short work with not over 0.010 or 0.012 in. to be removed from the diameter, it is advisable to set the wheel to grind the correct diameter and then grind the succeeding pieces without changing the cross-setting of the wheel, except occasionally to compensate for the wear of the wheel. This is spoken of as "*set-wheel*" *grinding.*

In recent years plain grinding machines have been designed to permit of using wide-faced wheels, and in manufacturing operations it is not uncommon to find wheels with up to 8 in. of face. When the work is shorter than the width of the wheel face, it does not have to be traversed, it is only necessary to feed the wheel in as the work revolves. This is called *infeed* or *plunge-cut grinding.*

With the wide-faced wheel and a suitable fixture for dressing the wheel to a given outline it is possible to grind a more or less irregular surface as, for example, when crowning pulleys, finishing handles, etc. This is termed *form grinding.* Form

grinding is not recommended for work having sharp corners to finish or where the difference between the largest and smallest diameters of the work is over ½ in.

Centerless grinding is discussed on page 401.

303. Factors in Successful Grinding.—The beginner in grinding is quite likely to think that too much emphasis is put on the *wheel*. It may seem that a great deal of time is taken to explain about the *making* of the wheel, the *selection* of the wheel for the job, the *care* of the wheel, and the *action* of the wheel. But it must be remembered that in no other machine is the cutting tool so preponderantly a factor in efficient operation. For example, a machinist, to do a good job of drilling or milling, does not have to select a twist drill or milling cutter of a certain kind of high-speed steel, and with a certain grade, grain, and structure—one cutter or drill for cast iron, another for steel; but, in grinding, the kind of wheel, and the grain, grade, and structure, are very important.

In any grinding operation, the rapidly revolving abrasive wheel is the cutting tool. The surface speed of the wheel, in feet per minute, is called the *wheel speed*. In external cylindrical or taper grinding, and in a large number of internal jobs, the work revolves, and in most surface grinding the work passes under the wheel. The speed, in feet per minute, that the surface of the work is being ground, is called the *work speed*. The direction of the revolving work, as in cylindrical grinding, is *against* the wheel rather than with it; in reciprocal surface grinding, a cut is usually taken in both directions—one with, the other against, the direction of the wheel.

It should be made clear that the best wheel *acts* best only when the *total* of wheel, wheel speed, work speed, and cut (feed) is right. That is, each depends upon the other; changing any of the last three will serve to change the *action* of even an ideal wheel. While this may seem, at first, to draw the line very fine, it really is fortunate, because it works both ways—if the wheel is not quite the best for the purpose, its action may be improved by changing the work speed, or possibly the wheel speed.

In production grinding, the wheel of known classification, the wheel speed, and the work speed are decided upon, the setup made, and production goes forward. The foreman must know about the selection, care, and use of wheels. In general machine work and tool making, the man on the machine must know how to select the wheel, mount it on the machine spindle, dress it properly, set up the job, and grind the given surface.

In addition to its shape and size, the factors to be considered in the selection of a grinding wheel and the setup for a given job are: (1) The kind of wheel (the bond) to use. (2) The kind of material to be ground; whether to use a wheel made of aluminum oxide or silicon carbide. (3) The arc or area of contact, for example, whether external, internal, or surface grinding. (4) The finish desired. On these factors depend: (5) The grain, grade, and structure of the wheel. In getting the wheel ready, setting up, and starting to grind, the considerations are: (6) Mounting the wheel. (7) Dressing the wheel. (8) Setting the wheel speed. (9) Setting the work speed. (10) Setting the amount of cross-feed. (11) Setting the table traverse (long feed). (12) Setting the table-reverse dogs. These factors may appear involved, but they are not difficult to understand if one enters, step by step, into the reasons underlying each. Explanations follow.

304. The Kind of Wheel (Bond) to Use.—The kind of bond a grinding wheel should have depends upon the nature of the job, whether, for example, it is snagging or precision grinding, infeed grinding with a wide-faced wheel or cutting off with a very thin wheel. It depends, also, upon the material to be ground, and, in some cases, upon the finish desired on the given material.

Three quarters or more of all grinding, both roughing and finishing, is done with *vitrified* process wheels, but these wheels are not as strong or elastic as the rubber- or shellac- or resinoid-bonded wheels.

With *rubber* as a bond, it is possible to make both very thin wheels and wide-faced wheels. The thin wheels are used

generally for cutting off and for slotting, and the wide-faced wheels for snagging castings. Rubber wheels are also used where a fine finish is required, such as on ball races, and are used almost exclusively as regulating wheels on centerless grinding machines.

Wheels bonded with *shellac* are used for grinding slate or marble and other stone. Also, they give an excellent finish on cast-iron, chilled iron, brass, and copper rolls. The toolmaker uses these wheels in bench-lathe-grinding attachments. They cut freely and give an excellent finish on copper, brass, iron, or on hard or soft steel.

Resinoid bond is hard and strong and fairly elastic. Wheels bonded with this material (Bakelite) can be made very thin and can be run safely at high speeds (up to 15,000 s.f.p.m.). They are used for cutting off bar stock of all kinds of steel and other materials. The wider-faced wheels are used in snagging castings, and are very efficient at high speeds. They are used in the final grinding operations on cams and rolls and other surfaces requiring a fine finish, and are found efficient in saw gumming and in grinding slate, granite, marble, and other stone.

Silicate-bonded wheels are used in grinding fine-edged tools, particularly knives. They can be made in large sizes and are smooth-cutting and cool-cutting.

305. Material to Be Ground.—It has been found that wheels made of aluminum oxide are best for materials of high tensile strength, because these crystals are tough and do not fracture under the great shearing stress, or cutting pressure, required for these materials. Therefore, use aluminum oxide wheels for grinding the following:

Carbon steels.	Annealed malleable iron.
Alloy steels.	Wrought iron.
High-speed steels.	Tough bronzes.

Use silicon carbide wheels for materials of low tensile strength, because these crystals, while being brittle, are tough enough to stand the stress required, and being harder

than aluminum oxide, will last longer. This abrasive is used for grinding the following:

Gray iron.
Chilled iron.
Brass and soft bronze.
Aluminum.
Copper.
Marble and other stone.
Rubber.
Leather.
Glass.
Stellite.
Cemented carbides (in the absence of a diamond wheel).

NOTE: For trade names of aluminum oxide and silicon carbide wheels see page 356.

306. Arc and Area of Contact.—The distance the cutting edge moves through the metal while peeling off its chip is the arc of contact of the wheel and work. As the diameter of the work increases, the given wheel has a longer arc of contact, cuts a longer chip. Removing the same amount of metal in a given time taking *longer* chips means taking *thinner* chips. Taking a long thin chip requires less cutting pressure than removing the same amount of metal by a shorter thicker chip. Hence, the given wheel will wear longer, that is it will *act* harder, when grinding the longer chips off the larger diameters. For instance, a wheel that is right for tool steel 1 in. in diameter at 25 ft. per min. will appear too hard when grinding tool steel 3 in. in diameter at 25 ft. per min. This is why it is advisable to use softer wheels for larger diameters, still softer for surface grinding and softer yet for internal grinding.

The same reasoning holds true with respect to variations in *area of contact*. In surface grinding, for example, with cup or with cylinder wheels, the area of the wheel and work contact is much greater than in cylinder grinding, or than it is in surface grinding with a straight wheel. The larger the area of contact the softer the wheel should be. Further, the larger or broader the contact, the greater must be the "chip clearance" to avoid excessive heating of the work. Chip clearance may be increased by using a coarser grain or a more open structure, or both.

307. Finish.—A fine grain will give a better finish than a coarse grain. Also resinoid-, rubber-, or shellac-bonded wheels are best for a high finish. These statements must not be taken to mean that special wheels are necessary for a high degree of commercial finish. As a matter of fact a vitrified wheel with medium grain or even a fairly coarse grain will give an excellent finish if machine conditions are right and the wheel is properly dressed.

308. Grade of Wheel.—The ideal wheel for the work in hand would be self-sharpening. That is, the pressure of the cut would break away the crystals at exactly the time they became too dull to do the given job in a satisfactory manner. To produce a suitable finish on hard materials, a sharper cutting edge is required than is necessary for softer materials, therefore a soft wheel, in which the slightly dull particles of abrasive will more easily break away under the cutting pressure, is used in grinding the harder materials such as cast iron, most of the alloy steels, and hardened steel.

Unhardened carbon steel and untreated machine steel and alloy steel may be economically ground to an excellent finish with cutting points that are worn somewhat duller than would produce an acceptable finish on the harder materials, therefore a wheel somewhat harder, a medium-grade wheel, that will retain its cutting particles longer, even until they are fairly dull, may be used on soft steel.

In grinding the still softer materials such as brass, bronze, copper, hard rubber, etc., the pressure of the work against the wheel is not so great as in grinding soft steel; therefore a soft wheel must be used or the cutting particles will be retained too long. Also a hard wheel is apt to fuse the chips, become clogged and glazed, and heat the work.

Softer grades of wheels are used in proportion as the penetration (depth of cut) or the arc of contact is increased. For example, a softer grade of wheel is used to grind a large diameter than is used to grind a small diameter, other things being equal, since the arc of contact is greater. For the same

reason, surface grinding requires a softer wheel than cylindrical grinding on the same materials; and internal grinding, where the arc of contact is still greater, requires a still softer wheel. The mistake most often made in selecting grinding wheels is to get them too hard. It is a false notion of economy. Better have a wheel too soft than too hard.

309. Grain of Wheel.—Very fine-grain wheels are seldom used except for the hardest materials and the finest finishes. Grain sizes from 60 to 120 are used, for example, in grinding cemented carbide tools. A fairly soft-grade wheel, with open-structure vitrified bond, will cut free and cool, stand up well, and give an excellent finish.

The idea that a fine-grain wheel is necessary to give a fine finish on the general run of grinding work is wrong. A coarse-grain wheel penetrates easier and cuts more freely than a fine-grain wheel. A comparatively coarse grain (24 to 46) gives satisfactory results in nearly all grinding operations, both for amount and accuracy of work, and also for finish. A coarse-grain wheel will best serve to rough out the work, because the penetration can be deeper, and a suitable commercial finish can be obtained with a wheel as coarse as 24 grain if carefully dressed. The tendency is to get away from the finer wheels, as it is also to get away from the harder wheels. If, however, an exceptionally fine finish is required, it may be advisable to rough-grind the pieces with a coarse wheel and finish them with one of finer grain.

For a variety of work, in run-of-shop jobs, the *combination wheel* is recommended. The combination wheel is made up of grains of different sizes, for example, one of the numbers 24, 30, 36, with 60 or 80. The combination gives a wheel that will hold its shape longer and give a better finish than a coarse-grain wheel; and it will cut faster and cooler than a wheel made entirely of the finer grain.

310. Structure.—As a chip is cut off the work by the grinding wheel it must have room to free itself or it will clog the wheel. An open porous structure of the wheel gives it this

free-cutting characteristic. Also it adds to the ability of the edge or corner of the abrasive crystal to penetrate, thus giving, generally, a longer life to the wheel.

For the very hard and brittle materials (carbides excepted), for most form-grinding wheels, and for the finest finishes on softer materials, a close spacing of the grains is recommended.

A wide spacing is best for the soft, tough, and ductile materials, especially in surface grinding. On cylindrical, centerless, and cutter grinding, wheels of either medium or wide spacing are satisfactory.

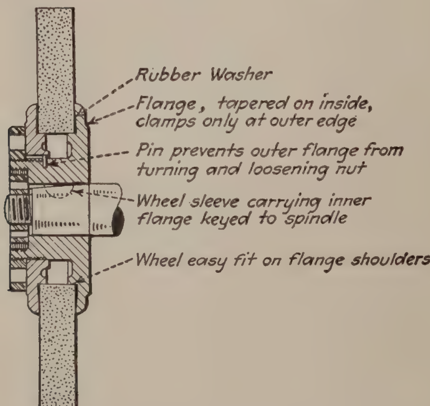


FIG. 286.—Mounting an abrasive wheel.

311. Mounting the Wheel (Fig. 286).—A wheel should fit easily upon the machine spindle (or wheel sleeve), yet not loosely, for if loose, it cannot be accurately centered and is consequently out of balance. Paper should be wrapped around the spindle to make a wheel fit when the hole is too large. On the other hand, a wheel that fits a trifle tight should never be forced on a spindle as this may cause it to crack.

If the hole is only a slight amount under size, it can be easily enlarged with an old file; or, if lead-bushed, a jack-knife can be used to cut out enough metal to make the wheel fit easily on the spindle.

The flanges between which the wheel is secured should be at least one third of the diameter of the wheel; it is better to have them nearer one half that diameter. They should be relieved on the inner side, so that they bear against the side of the wheel only at the outer edges. This serves to hold the wheel more securely with less pressure on the nut and with less likelihood of breaking the wheel. The inner flange should be keyed, or otherwise fastened securely to the wheel sleeve to prevent it from turning and loosening the clamping nut.

Washers of leather, blotting paper, or rubber should be placed between the bearing surfaces of the flanges and the

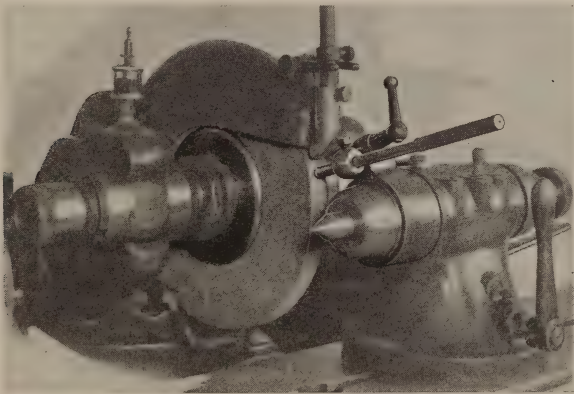


FIG. 287.—Dressing the face of a grinding wheel.

wheel. Some makers attach a ring of heavy blotting paper to each side of their wheels for this purpose, but it is a good plan to use a leather or rubber washer in addition.

312. Truing and Dressing a Grinding Wheel (Fig. 287).—These two terms were formerly synonymous but are now used to indicate two distinct purposes. *Truing* is the operation of *shaping* a wheel to make it run true, or to give it a desired shape. *Dressing* is the operation performed to make the wheel cut better; it may be strictly a *sharpening* operation, when the crystals in the wheel face become too much dulled before automatically breaking away; or it may be a necessary *dressing* operation when the wheel is "loaded" (see page 384).

It should be stated here, that while the ideal wheel would "automatically sharpen," that is, the crystals, when just sufficiently dulled, would either fracture or entirely break away from the face of the wheel and thus present new cutting edges, this ideal condition is only approached in practice, and therefore occasional dressing is required.

313. Types of Wheel Dressers.—There are many types of wheel dressers manufactured: (1) With hardened wheels or disks in a suitable holder, such as the Huntington or Standard, used for offhand dressing of wet-grinder wheels and snagging wheels. (2) With special silicon carbide abrasive wheels mounted in high-grade bearings in a suitable holder, such as the Ross or Place. This type dresses wheels to give an excellent commercial finish in the heavier plain or centerless grinding machines. (3) Abrasive stick dressers, either regular or magazine, much used in toolrooms for wheels for cutter grinders, bench grinders, etc., for both truing and dressing. (4) The diamond tool, which is best for truing and dressing wheels for precision and high-finish grinding.

314. The Diamond Dressing Tool.—There are many ways of mounting the diamonds, single and multiple, in the various shapes and kinds of holders. These commercial practices cannot be treated here, but a word may be said about the diamond itself, and a few directions given for its use.

Industrial diamonds, unsuitable for gems for one reason or another, are of two general kinds, the *black diamond* (carbonado) and the *bort*. The black diamond is the hardest known substance, harder than any gem diamond or bort. They are found mostly in Brazil. Most of the borts come from the diamond mines in South Africa, but are not usable for cutting into gems.

The effectiveness of diamonds is largely dependent upon the shape, and the shape upon the cleavage planes. The black diamonds have no distinct cleavage planes, are cross grained and therefore blunter. They are used in rock drills etc., while *borts*, having sharper cutting edges, are preferred for machine-shop use, both as grinding-wheel dressers and

as cutting tools for fiber, hard rubber, vulcanite, and other materials that dull steel tools so quickly. They are used also in making diamond wheels (see page 366). Brown borts are recommended for average wheel-dressing tools.

315. Directions for Using the Diamond Tool.—1. Provision is usually made for holding the diamond tool in the machine or by means of an attachment, and, except when unavoidable, the wheel should never be dressed "by hand."

2. Do not use a small diamond on a heavy wheel.

3. Be sure the diamond itself is securely held before taking the diamond tool from the tool crib.

4. The diamond tool should be securely and rigidly held, with minimum overhang, and "canted" a 5- or 10-deg. angle, that is, with the handle raised as in *a*, Fig. 288. Canting it in this way avoids chattering and the tendency to "dig in." If in doubt as to the wheel center line, lower the tool ⅛ in. for safety.

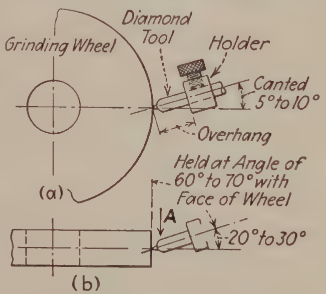


FIG. 288.—Dressing a grinding wheel.

5. Also it is preferable to hold the tool about 60 or 70 deg. with the face of the wheel as in *b*, Fig. 288. Feed against the point (arrow *A*) for the first one of two passes, and in the opposite direction for the very light finishing cut.

6. Do not use one spot on the diamond too long; a changed contact on the wheel each setting will tend to keep the diamond sharp. A dull diamond will not properly dress a wheel.

7. In the setup of the diamond tool, *be sure that the holder will not be touched by the wheel.* It is very easy to grind away the "setting" and lose the diamond.

8. Do not overheat the diamond; use plenty of coolant or, if dry-grinding, allow cooling intervals.

9. Move the diamond across the face of the wheel quite slowly.

10. Do not have diamond cuts over 0.001 in. deep.

GRINDING PRACTICE

316. Setting the Work.—Measure the first piece, or pieces, and do not grind any one to size before the machine is correctly set for the job. That is, do not run the chance of spoiling the first piece, or even the second, by grinding too close to size before the machine is set right.

The amount of stock to be left for the grinding operation depends largely on the character of the work, whether the piece is long or short, stocky or slim, what the material is, if it is to be hardened, what the facilities are for straightening, and the nature of the turning (whether it is fairly smooth or not). It might be good practice to leave only 0.005 in. on one piece, while on another piece it would be economical to leave $\frac{1}{32}$ in. for grinding. This is a matter of judgment and requires experience. Manufacturers usually supply limit gauges[1] to the lathe hands who rough-turn the work. Have the centers and center holes in first-class condition and *clean.* If the work is to be chucked or held in a vise or clamped otherwise, have the holding device and the work clean, and be extremely careful in clamping. Remember that a very little dirt or a slight stress that will twist or buckle or bend the work will defeat good grinding.

317. Setting the Wheel Speed.—A speed too slow causes the wheel to act too soft and wastes it. Too fast a speed causes a hard grinding action and may cause the wheel to break. The surface speed of an abrasive wheel with either vitrified or silicate bond should be from 6,000 to 6,500 s.f.p.m. It may be advisable to run it slower to have it act softer, but it is dangerous to run it faster than 6,500 s.f.p.m.

Wheels with organic bonds may be run faster; certain cutting-off wheels with resinoid bond may be run at 15,000 s.f.p.m. The maximum safe speed is printed on the ticket

[1] *Limit Gauge.*—A double gauge having one dimension larger and the other smaller than the nominal size. With narrow limits these gauges are valuable for testing the finished product. They are also much used in lathe work (rough turning) with wider limits over and under the nominal turning dimension.

with the new wheel. With an old wheel, when in doubt play safe (6,500 s.f.p.m.).

Do not get revolutions per minute confused with surface speed. As the size of the wheel decreases noticeably the revolutions per minute may properly be increased. Remember always that when a wheel of larger diameter is substituted for a smaller wheel, the speed of the spindle should be *decreased.*

Rule I.—To obtain surface speed, diameter of wheel and revolutions per minute given, multiply revolutions per minute by one fourth the diameter of the wheel or

$$\text{Surface speed} = \text{r.p.m.} \times \tfrac{1}{4}\ \text{dia.}$$

Rule II.—To obtain the necessary number of revolutions per minute to give the desired surface speed, having given the diameter of the wheel, divide the surface speed required by one fourth the diameter of the wheel, or

$$\text{r.p.m.} = \frac{\text{surface speed}}{\tfrac{1}{4}\ \text{dia.}}$$

For derivation of formulas see paragraph 198, page 241.

318. Setting the Work Speed.—The grinding wheel can do only so much cutting. Bearing a tool too hard on the wet grinder does not sharpen it any faster but does result in wearing the wheel and possibly in overheating the tool. By the same principle, revolving the work too fast (which has the same effect as bearing too hard) in the grinding machine does not produce more work but results in wearing the wheel and possibly in injury to the work.

There is a ratio between the work speed and the wheel speed that will result in an efficient wear of the wheel, and this ratio may be approximated in any grinding machine. It is this ratio of work speed to wheel speed that determines the forces acting on the wheel face that tend to break or dislodge the crystals of abrasive, and by regulating one or the other of these speeds (preferably the work speed) the approximate balance or ratio to give the ideal "breaking down," or automatic sharpening action, may be obtained. Thus, as the work

speed is increased in ratio to the wheel speed, the stresses are increased and the wheel *acts* softer, that is, it is broken down faster. Therefore:

1. If, in grinding, the wheel acts too soft—wears rapidly, does not hold its size—decrease the work speed (or, possibly, increase the wheel speed).

2. If the grinding wheel acts too hard—glazes, and heats the work too much—increase the work speed (or, possibly, decrease the wheel speed).

As a help to the beginner the following table of (average) work speeds is given:

SURFACE SPEED OF WORK IN FEET PER MINUTE

Operation	Soft steel	Hardened steel	Cast iron	Bronze
Roughing..........	50	25	40	60
Finishing..........	75	40	60	75

For finishing, the cut is lighter and the work speed may be increased as noted in the table.

319. Setting the Table Feed.—The more cutting edges of a suitable wheel that come in contact with the work in a given time the greater the production. Consequently, in traverse grinding, if the nature of the work will permit and maximum production is expected, the table feed for roughing should be arranged to move the work an amount slightly less than the width of wheel face each revolution of the work. When finishing, the work speed is increased and the table traverse is usually unchanged, which results in a feed considerably less than the full width of the wheel face.

Where possible, it is a good plan to set the reverse dogs to allow a portion, if not all, of the wheel face to extend beyond the end of the surface being ground.

In universal grinding machines the width of wheel used is not usually over 1 in., but plain grinding machines are built which take a wheel with a 10-in. face. When the length of the surface being ground is less than the face of the wheel it is

unnecessary to traverse the work. The infeed method of grinding is used (see paragraph 302).

320. Setting the Depth of Cut.—Given a wheel of proper grain and grade, the right wheel speed and work speed, then the depth of cut is limited only by the nature of the work and the power of the machine. The idea that, in grinding, a series of infinitesimal cuts should be taken is wrong. It is safe to say 1,000 cuts are taken that are too light to one that is too heavy. The usual faults in infeeding are (1) irregular hand feed and (2) too light a feed. It is practically impossible to feed by hand without sometimes feeding too much and at other times too little; *use the automatic feed.* Do not take one tooth of feed for roughing, take eight or ten teeth; and very likely the job will stand twice that or even more.

321. Causes of Inaccurate Work and Imperfect Appearance. Time may be wasted and poor work result by the use of a wheel so soft that it will not hold its shape the whole length of cut. This is especially true in surface grinding. Most of the spoiling of ground work is, however, caused by the heating and consequent warping of the work, owing to a hard wheel, a dull wheel, or a loaded wheel. Chatter and waviness in the work may be caused by the wheel spindle being loose in its bearings, the wheel out of balance, or the wheel being clogged with chips, but the most frequent cause is the wheel getting out of shape, either out of round or the face not parallel to the cut. *Keep the wheel clean and true and sharp.*

322. Causes of Wheel Wearing Too Rapidly:

1. Wheel too soft.
2. Face of wheel too narrow.
3. Speed of wheel too slow.
4. Speed of work too fast.
5. Crowding the wheel.
6. Holes or grooves in the work.

323. Causes of Wheel "Glazing."

1. Wheel too hard.
2. Grain too fine.
3. Wheel speed too fast.

4. Work speed too slow.
5. Wheel loaded with chips.

324. Causes of Wheel Getting Loaded.—When grinding soft materials such as brass, bronze, aluminum, or even soft steel, there is a tendency for the chips to wedge in between the cutting points of the wheel in the same way that a file is loaded. This is especially true when the wheel has too dense a structure, or is too hard, or when the work is running too slow. The remedy is to do one or more of the following: Select a softer wheel or one with more open structure; increase the work speed; decrease the amount of chip, and perhaps the amount of table feed if the width of the cut seems to cause the work driving belt to slip.

325. The Advantage of Using Dead Centers in Grinding.—The work, revolving with the headstock spindle, may be held on centers, in a chuck, on a faceplate, or directly in the taper hole of the spindle. In addition, the grinding machine is provided with means of driving the work on dead centers.

The work itself having good clean centers and ground *on dead centers* in the machine must come true and absolutely concentric. If, however, the live center revolves with the work, any fault in the spindle bearings will affect the accuracy of the work. Moreover, if the live center runs out ever so little, the work in being ground will be that much out of center or eccentric.

326. The Use of Back Rests or Steady Rests.—The back rest, or "steady rest," is necessary when grinding slender work (Fig. 289). Grinding-machine manufacturers have developed back rests with considerable flexibility when the work is in the rough, but which are provided with positive stops which insure the accuracy of the finished piece (see Fig. 291). That is, they may be adjusted to compensate for work which is considerably oversize, out of round, or slightly bent. When, however, a plain rest is used (and often with a compensating back rest) it is advisable to "spot" the work for the rest by feeding the wheel in by hand until the diameter is 0.002 or

0.003 in. oversize (see *A*, Fig. 290). This operation takes only a short time, eliminates much of the tendency otherwise for the work to chatter, and makes for longer life of the shoe.

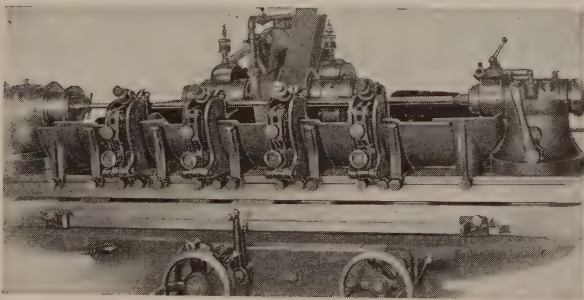


FIG. 289.—Shows back rests in use.

The detail in which Brown & Sharpe give the following instructions for the use of their back rest (Fig. 291) indicates the importance of care in the art of grinding.

To adjust the universal back rest proceed as follows:

First.—Select shoes the size of the finished work, and hook the trunnions 1 into the V-bearings 2.

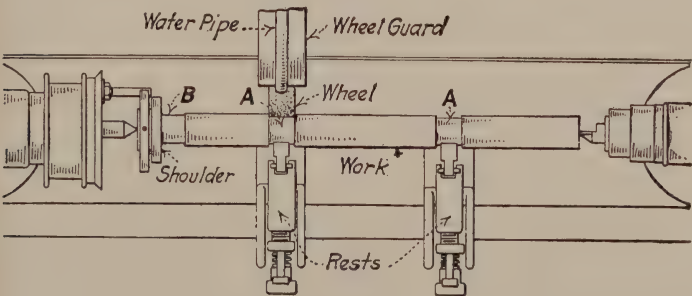


FIG. 290.

Second.—Turn screw 3 back far enough to allow the shoe to clear the work, and loosen nut 4 to relieve entirely the pressure on spring 5. Turn back screw 6.

Third.—Turn forward the screw 7 until a light pressure is given to the spring 8. Turn forward the screw 3, and, if the spring 5 is wholly

relieved and the screw 7 is far enough back, the shoe will come in contact with the work at both points *A* and *B*.

Fourth.—Press lightly with the thumb on 9, holding the shoe in gentle contact with the work, and turn the screw 6 carefully, noting the slightest touch of the end against the stop *C* in order that none of the parts be moved. With this screw in contact with the stop, the shoe should bear alike at both points *A* and *B*. Turn nut 4 to give some pressure to the spring 5. The combined pressure of the springs 5 and 8 should be only sufficient to resist the pressure of the

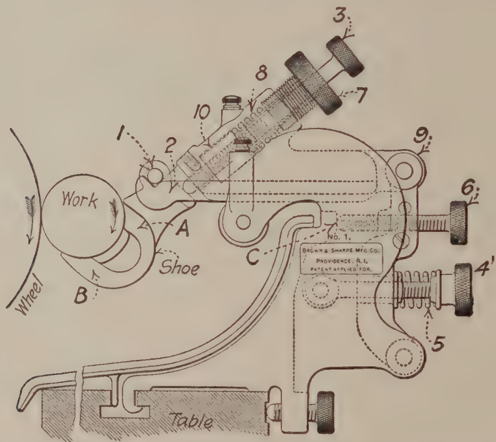


FIG. 291.—Brown & Sharpe universal back rest or steady rest.

wheel when taking the last cut and to prevent vibration of the work under any cut that it may be desirable to take. Tighten the clamping screw to hold screw 3.

Fifth.—Grind the trial piece of work, moving the screw 3 to maintain the contact of the shoe with the work and the screw 6 to preserve the relative diameters at the various points. As the work approaches the finished size, measure at the different rests, after each cut.

After the first piece is finished with the diameters alike at all points, the shoe should bear alike at *A*, and *B* and the sliding nut 10 should rest against the shoulder.

Leave the parts in this relation and grind the other pieces of work, adjusting screw 3 only as the shoe wears and screw 6 for the delicate adjustment for diameter. Note the effect of the adjustment upon the sparks to determine the approximate position.

When work is to size, the nut 10 and the screw 6 are intended to rest against the shoulder and stop to prevent further pressure of the shoe upon the work. The shoe and wheel will be left in the proper position for sizing duplicate pieces.

When unground work is placed on the centers and in the shoe bearings, the nut 10 and screw 6 will be forced away from the shoulder and stop, thus compressing the springs 5 and 8.

Should the shoe bear unequally on *A* and *B*, tighten screw 4 to increase pressure at *A*, and screw 7 to increase pressure at *B*. Do not make the combined pressure of these springs greater than necessary, as long and slender work, although of uniform diameter, may not be straight when released from the shoe unless some allowance is made for elasticity.

327. Roughing and Finishing Cuts.—In the modern grinding machine the work speed, cross-feed, and table feed are independent of each other. That is, any desired table feed, coarse or fine, may be used on work of any diameter, the work, of course, revolving at the proper speed for that particular job. The cross-feed may be set for any desired amount. Consequently the combination of work speed, table feed, and cross-feed may be used that in roughing will serve to most quickly remove the metal, and in finishing will give the kind of surface desired.

It will, of course, depend upon the size of the work, the number of pieces, the degree of accuracy required, etc., whether it will be better to rough and finish in one setting, or to rough all the pieces before finishing any. In either case it will be advisable to take two or more light cuts when finishing. It will be advisable also to decrease the table feed to two thirds or three quarters of the roughing feed.

328. The Use of Cutting Lubricant in Grinding.—Provision is made in most grinding machines for keeping a steady flow of cutting lubricant directed on the part of the work where the wheel touches.

In the smaller types of grinding machines, cutter grinders and toolmakers' surface grinders, etc., this feature is not provided, but in the external- and internal-cylindrical-grinding machines and larger surface-grinding machines, it is an abso-

lute necessity. An uneven temperature of the work will cause distortion and a consequent inaccuracy. The flow of compound serves to prevent this and serves also to keep the wheel clean and free-cutting, which makes for greater production.

There are several specially prepared compounds in the market which, when mixed with water, are very satisfactory, and the grinding-machine or abrasive-wheel manufacturers are glad to recommend certain brands.

If clear water is used, it will rust the machine and the work, and to prevent this just enough sal soda is added to show a slight deposit on the finished work when dry. Many machinists add a small quantity of oil, which serves to give a better finish on the work.

Questions on Grinding, I

1. What do you understand by the terms "grinding" and "polishing?"

2. What do you understand by "commercial grinding?"

3. What do you understand by "efficient grinding?"

4. State at least five things necessary to accomplish a real job in grinding.

5. What is meant by traverse grinding? Set-wheel grinding? Infeed grinding?

6. Is form grinding infeed grinding? Explain.

7. Can you explain why understanding the construction of the machine will increase your production? Can you give an example?

8. Can you state why habits of reasonable care will increase production?

9. What does increased production mean to you personally?

10. Should the surface speed of a grinding wheel be more or less than a mile a minute? About how much? What do you understand by a "safe" speed?

11. How many revolutions per minute will be a safe speed for a 10-in. wheel?

12. How do the work speeds for roughing and finishing soft steel, cast iron, and bronze in a grinding machine compare with speeds for turning these materials in a lathe?

13. Why is it that a soft wheel is used for grinding hardened steel and also for the soft materials such as bronze and copper, while a harder wheel is used on machine steel, a material of medium hardness?

14. A wheel may act harder or softer according to the work speed. How do you account for this?

15. Why are softer wheels used for larger diameters than for smaller diameters of the same material?

16. Does the same principle (as in question 15) apply in surface grinding and internal grinding? Explain.

17. What effect in grinding has the *grain* of the wheel?

18. A few years ago the machinist set the table traverse to feed anywhere from $\frac{1}{1000}$ to $\frac{1}{64}$ in. per revolution of the work. What is the modern practice? Have you tried it?

19. Also it was the practice to take about half a thousandth chip. What is the modern practice in efficient grinding?

20. Occasionally it is advisable to feed the wheel in by hand, but usually it is best to use the automatic cross-feed. Explain.

21. Why is a coarse wheel used in roughing? Why is a coarse wheel satisfactory for many finishing operations?

22. What is the advantage of the combination wheel?

23. What is meant by penetration?

24. On one job it may be advisable to leave $\frac{1}{32}$ in. for grinding, on another job only about 0.005 in. How do you explain this?

25. What is the advantage of having work speed and table traverse independent of each other?

26. If you had, say, 100 pieces, easy to handle, how would you proceed to rough- and finish-grind them? Why?

27. Might it be advisable to rough and finish larger, heavier pieces in a different way? Explain.

28. If production is not up to standard quantity and quality, what would you suggest as possible causes?

29. What do you mean by a wheel being loaded? What does it indicate?

30. How do you account for a wheel becoming glazed?

31. How are wheels wasted?

32. What is the primary reason for using cutting lubricant? State two other reasons.

33. Explain the advantage of grinding work on dead centers.

34. Do you understand the value of back rests? Do you understand the construction and adjustments of the back rests on the machine you are using?

35. Having studied this subject thus far, just what are your ideas concerning a superior grinding machine? The best wheel to use? An intelligent operator?

GRINDING OPERATIONS

329. A Few Suggestions.—1. Be sure the wheel is guarded.

2. Do not use a wheel that is not sound. Tap it lightly with a hammer and listen for a clear ring.

3. Remember to change the revolutions per minute of the wheel spindle if a larger or smaller wheel is substituted.

4. Always dress a wheel after substituting it for another; running out ever so little will defeat efficient production.

5. If the wheel does not go on the spindle easily, scrape the lead bushing a little, perhaps with a pocket knife.

6. Never take a diamond tool away from the toolroom without first making sure the diamond is firmly held in the holder. You may get charged for a diamond you did not lose or you may lose a diamond someone else has loosened.

7. An abrasive wheel, like any other cutting tool, gets out of shape and dull, dress (sharpen) it occasionally.

8. See that the grinding-machine centers are smooth and clean and that the work centers are in good shape, cleaned from dirt, and well oiled.

9. Be careful to *know* that the table-feed-reverse dogs are correctly adjusted.

10. When setting up, cleaning, or oiling, it may be necessary to move the table by hand. Move the wheel out of the way first.

11. Do not forget that moving the table lengthwise is likely to stretch the belt from the overhead pulley drum to the headstock unless the belt is running. Pull the belt by hand if necessary.

12. Clean the swivel table thoroughly before moving the tailstock or headstock.

13. Don't attempt to grind when the belts slip; pay especial attention to the wheel-driving belt.

14. Always keep measuring tools and gauges covered when not in use.

15. When finish-grinding if it is necessary to stop the machine for a considerable time as for lunch or overnight, do not start to grind as soon as the machine is started. Many pieces have been spoiled in this way. Let the machine run for 5 min. and warm up.

330. Operations in Grinding a Cylinder.—1. Be sure the wheel is true and sharp. If in doubt use the diamond.

2. Fasten the suitable driver on end of work.
3. Clean and oil both centers of work.
4. Bring tailstock to position (so that tail center has proper tension against work).
5. Adjust the right reversing dog so that a portion of the face of the wheel runs over the end of the work, and the left reversing dog so that the side of wheel will approach nearly to work driver.
6. Note the wheel speed.
7. Set the work speed.
8. Set the table feed.
9. Set the automatic cross-feed.
10. Spot for the back rests if necessary.
11. Adjust the back rests.
12. Rough-grind to within 0.003 to 0.005 in. oversize.
13. Set the cross-feed automatic stop (first piece only).
14. After pieces are rough-ground as above, change position of left reversing dog as desired, reverse the work on centers and rough-grind other end of each piece.
15. When all pieces are rough-ground, change the table feed, the cross-feed (and possibly the wheel), dress the wheel, and proceed to finish practically as for roughing.

331. Grinding a Shouldered Piece.—(*Caution:* Owing to the probability that the center holes are not exactly the same depth in a number of shouldered pieces to be ground, or that, as in the case of a shouldered bushing, the pieces do not locate in the same position on the mandrel, great care must be taken not to allow the wheel to run into the shoulder.)

Where the width to be ground is less than the width of the wheel, it is most economical to feed the wheel in laterally by hand until the work is down to size, and then slowly run the work off the wheel (table traverse) to remove any lines caused by the wheel surface.

When grinding any considerable length of work to a shoulder, the portion next to the shoulder should be finished to size by feeding the wheel in laterally by hand (see *B*, Fig. 290), and

then, drawing back the wheel, finish the remaining portion in the usual manner of table traverse and automatic feed.

The table-traverse reverse dog should be set to operate about $\frac{1}{16}$ in. or more from the shoulder. While the table-reversing dogs operate to reverse the table motion within a few thousandths, they do not form a positive stop, and by means of the traverse handwheel the table may be easily moved $\frac{1}{16}$ in. or more beyond the regular travel, which fact makes possible the cut close to the shoulder, as above explained, without moving the dog.

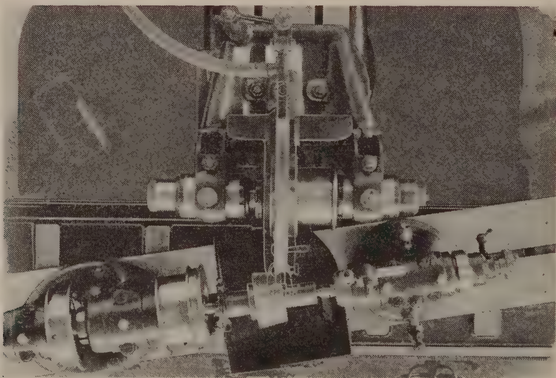


FIG. 292.—Grinding a taper.

It will be more economical if shouldered pieces that are to be ground on the smaller diameter are previously turned (necked) to size or slightly smaller for a distance, depending on the diameter, of $\frac{1}{8}$ in. or more from the shoulder.

Cutting with the corner of the wheel tends to round that corner, "dragging" the other corner tends to keep it sharp. In other words, if the work is fed against the wheel in one direction only, the edge of the wheel feeding against the chip will become slightly rounded, while the other edge will stay square. Therefore, when a particularly sharp corner is required between the shoulder and the smaller diameter, and no previously turned neck is provided, it is usually best to do all or most of the cutting while feeding away from the

corner. It is usually advisable to feed the shorter pieces by hand.

332. Grinding a Taper.—Tapers up to 2 in. per ft. may be ground by setting the swivel table the desired amount, as shown in Fig. 292. Remember the graduations are for convenience and do not depend absolutely upon them; *fit the taper to a gauge.* If difficulty is experienced in getting the swivel table adjusted exactly and the first piece is ground nearly to size, do not take a chance on spoiling this piece but put in another (unground) piece and try to get the exact fit

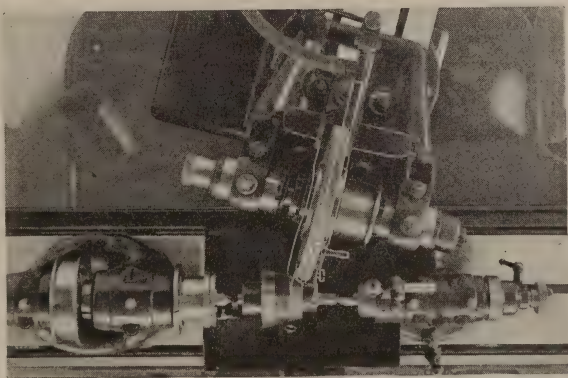


FIG. 293.—Grinding an angle. For a diagram of the setup see Fig. 281.

while it is still somewhat oversize. The first piece can be finished without worry of spoiling after the table is set.

When grinding several tapers, shanks of end mills, for example, unless the center holes are all of the same size there will be a variation of the size of the taper, if the wheel is fed in a like distance for each piece. Grind the pieces with the larger centers (headstock end) first and thus avoid danger of grinding any piece too small.

333. Grinding an Angle.—In machine-shop work a piece is called a *taper* when it becomes uniformly smaller toward one end by an amount not over 8 or 10 deg., included angle (about 2 in. taper per foot), when it becomes uniformly smaller in greater degree it is called an *angle.*

To grind angles (work held on centers, Fig. 293), swivel the wheel-stand-slide bed to the required angle, then set the stand at right angles to the movement of the slide so that the face of the wheel is parallel to the surface to be ground. Operating the cross-feed will cause the wheel to feed in a direction at an angle to the axis of the work, according to the setting of the wheel-stand bed. To take a deeper cut, the *table* is moved a trifle by gently tapping the table-traverse handwheel. A setup for grinding an angle is illustrated in Fig. 293, also in the line cut, Fig. 281.

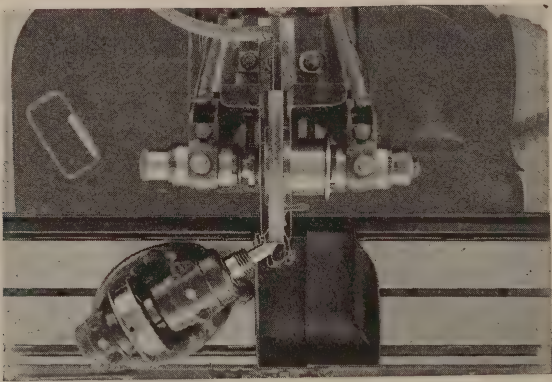


Fig. 294.—Grinding a center.

A center may be quickly and accurately ground by swiveling the headstock as shown in Fig. 294 and driving by the live spindle-driving pulley. In a similar manner a piece held in the chuck mounted on the head-stock spindle may be ground at an angle.

334. Face Grinding (Figs. 295 and 296).—The figures show two methods of face grinding. In Fig. 295 the side of the wheel is undercut a trifle, leaving a narrow cutting surface. (A wheel similarly trued away is shown in Fig. 303.) The swivel table is set straight, and the wheelhead-slide bed must be at right angles. Then the axis of the work arbor and the axis of the wheel spindle are parallel and the surface ground will be flat. A convex or concave surface may be obtained by varying the relation of the axes.

Figure 296 shows a method of grinding work flat or, if desired, a trifle thinner toward the center, as for example a metal-slitting saw. The work may be mounted on the face chuck and centrally located and securely held by means of an expansion bushing and draw-in bolt (Fig. 297). If more convenient, it may be held in a chuck. These accessories are usually furnished with the machine. If there is enough work of this character to warrant the cost of a magnetic chuck, no doubt such a chuck is most efficient. An ample flow of compound is necessary in face grinding if the work is thin, to keep it from warping.

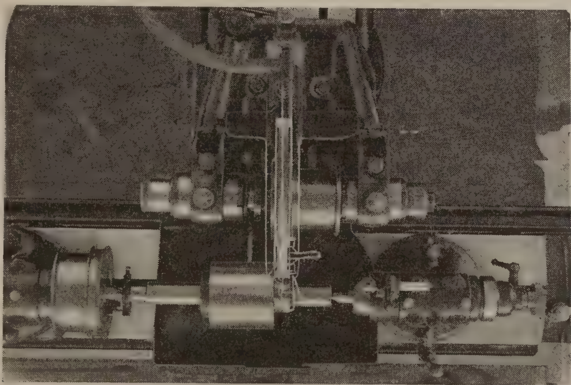


FIG. 295.—Squaring the ends of bushings or similar parts.

335. Internal-grinding Fixture.—If the number of holes to be finished in a manufacturing department will warrant the outlay, it is, of course, economy to have an internal-grinding machine (Fig. 270) of the kind and size desired. For the average general machine-shop and toolroom work, however, the internal-grinding fixture, with which all universal grinding machines are equipped and which may be quickly set up, will be found very satisfactory for either straight or taper holes. Figure 298 illustrates this attachment.

336. Internal Grinding.—Clamp the work carefully in order not to spring it in the slightest degree. As in cylindrical grinding have the work revolve against the wheel, that is

in an opposite direction to that of the grinding wheel. The spindle of the internal-grinding fixture runs from 10,000 to 16,000 r.p.m. (depending upon the size and kind), but even

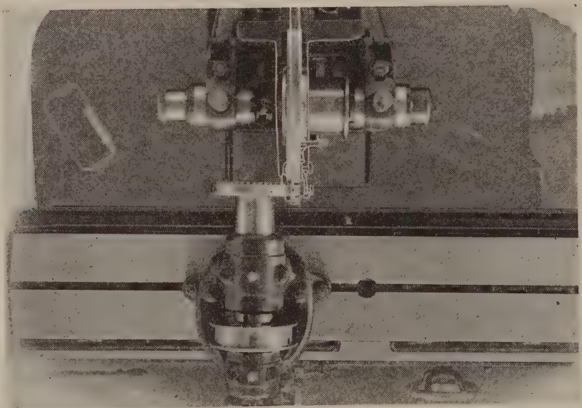


FIG. 296.—Face grinding using face chuck shown in section in Fig. 297.

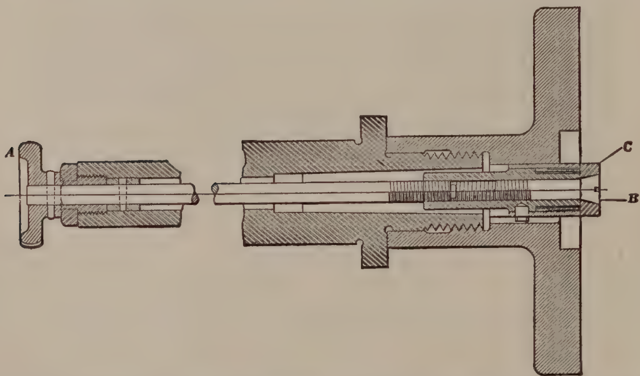


FIG. 297.—Section through headstock spindle (Brown & Sharpe), showing mechanism which operates face chuck. This chuck holds such work as thin cutters, saws, washers, etc. by means of an expansion bushing C which is expanded by the screw B and drawn tightly against the face plate by turning the knob A. Different sizes of bushings may be quickly substituted.

this speed will not give the proper surface speed to a small grinding wheel. For this reason, and for the further reason that so large a portion of the periphery of the wheel is in contact with the work, the work must revolve somewhat faster

than for outside grinding and the wheel should be free-cutting that is, fairly coarse and of very soft grade.

Generally speaking, the amount of metal left for internal grinding should be considerably less than for external grinding because inside grinding, especially in small holes, is much slower than outside grinding. If an extremely accurate straight hole is required, as for example in a ring gauge, it is better to leave a fin at either end as shown in Fig. 299. The fin is afterward removed and this will remove the slight "bell mouth" that occurs at each end of the hole.

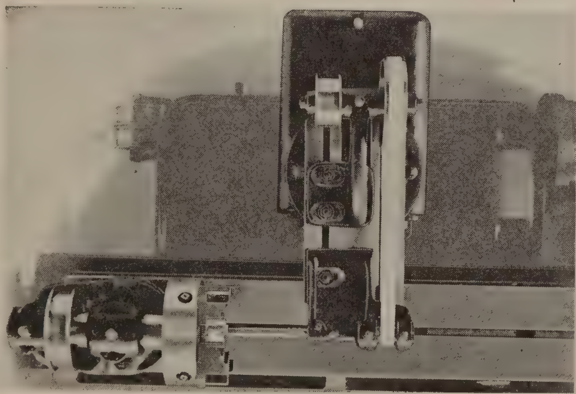


Fig. 298.—Internal grinding attachment in use in No. 1 universal grinding machine (Brown & Sharpe). The wheel stand is removed, the wheel-stand platen is reversed (swiveled 180 deg.), and the countershaft bracket and grinding fixture bolted to the platen as shown. The countershaft and fixture spindle are connected by a small open belt, and the belt from the overhead works to the countershaft is crossed to give the correct direction of rotation for the grinding wheel.

To find if the hole is being ground straight, proceed as follows: (1) Rough-grind the hole fairly straight until it is clean. (2) Move the cross-feed until the wheel just touches the opposite side of the hole. (3) With this setting, feed slowly lengthwise and note the sparks. (4) If the sparks are even, the hole is straight; if they are not even, adjust accordingly and repeat the entire operation.

337. Grinding Taper Holes.—Taper holes are ground in exactly the same way as straight holes, except that the swivel

table is adjusted to give the required taper. If a steeper taper than may be obtained by swiveling the table is required, the headstock may be swiveled.

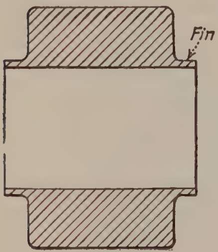


FIG. 299.

SURFACE GRINDING

338. Surface grinding is accomplished by fastening the work to the table of the machine and causing it to feed under the revolving grinding wheel. The principles of grinding as discussed in preceding pages apply to surface grinding as well as to any other kind of grinding.

Two types of surface-grinding machines are illustrated in Figs. 272 and 273. In the *horizontal-spindle machine* the

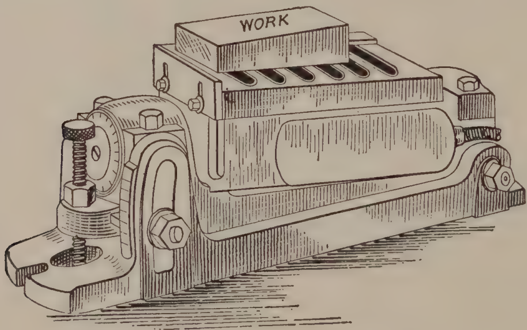


FIG. 300.—Magnetic vise or magnetic chuck.

Made in many sizes and styles, some of which are hinged on the end of a special base and may be provided also with facilities for tipping laterally in either direction. This forms a "universal" vise.

The face of the vise is made up of a number of magnet poles separated by nonmagnetic metal, and coils of insulated wire form these into electro-magnets when current is applied.

Rotary magnetic chucks are made for plain grinding machines, etc.

Current can be supplied from any lamp socket on a direct-current circuit; *alternating current cannot be used.*

Nothing but iron or steel can be held on the vise.

Do not use water except when vise is made for it.

Do not attempt to take the vise apart.

wheel cuts only a very slight amount for each forward and return movement of the table. The table speed is 30 or more ft. per min. The cross-feed is automatic at each end of the

work. In the *vertical-spindle machine*, the wheel has a considerably greater contact with the work, and the table motion is necessarily much slower.

In either type of machine, the work may be fastened to the table, clamped in a vise or special fixture, or held by means of a

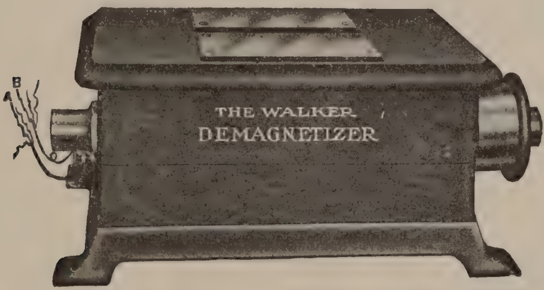


FIG. 301.—Hardened steel, and to a slight degree cast iron, coming in contact with the magnetic chuck, becomes permanently magnetized. On some classes of work this is found objectionable and the apparatus shown is provided for the purpose of demagnetizing the work when necessary. After first setting the demagnetizer in motion, practically all traces of magnetism are removed from the work by simply vibrating it several times in and out of contact with the metal plates at the top. This apparatus consists essentially of a magnet suitably held and revolving under a mass of laminated sheet-iron plates in contact with the two metal plates shown at the top. The phenomenon of demagnetizing may be briefly explained as follows:

The iron plates at the top of the apparatus represent the poles of a magnet in which the polarity is rapidly reversing. This reversal of polarity is transmitted to the work which is laid in contact. At the moment of reversal, however, there is a neutral point in which for an instant, there is no magnetism. In removing the work out of a strong magnetic field to a weaker one (by lifting it away from the apparatus), it has moved a certain distance during the time that the magnet is neutral, and the next time it becomes charged up, being in a weaker field, it does not take so strong a charge as before, and by repetition of this movement, the magnetism is finally removed. (*Courtesy of O. S. Walker and Company.*)

magnetic vise (Fig. 300). Magnetic vises are made in many types, shapes, and sizes.

Work held on a magnetic vise becomes more or less magnetized, and while reversing the current by means of a double switch serves to remove most of the magnetism, the demagnetizer (Fig. 301) is more efficient for this purpose and is recommended. Even with the demagnetizer, total demag-

netization does not occur, and this is a serious objection on certain classes of work, for example gauge work.

In such work the thin pieces that cannot be conveniently held in a vise or otherwise clamped may be held securely by a few drops of wax here and there along the corners between the edge of the work and the table.

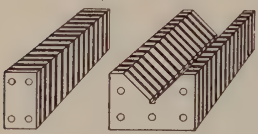


FIG. 302.—Examples of Karnetic parallels. (*Courtesy of Kar Engineering Company.*)

It should be understood that when using the magnetic vise for holding small pieces, or for work with a base small in proportion to the height, an abutting piece or back stop of sufficient base and suitable thickness or height should be used to keep the work from slipping or tipping under the pressure of the cut. A piece of sheet steel, say $\frac{1}{16}$ by 2 by 6 in., makes an excellent stop for the smaller pieces, and an angle plate with a base 3 or 4 in. square is very useful to support work that otherwise is likely to tip on the magnetic vise. Often it is best to clamp such work to the angle plate.

To hold, by the magnetism of the vise, a piece which rests on parallels, it is necessary to have special parallels. Such parallels are made of alternate laminations of magnetic and non-magnetic materials, for example, iron and fiber. These parallels become magnets by conduction and have about 80 per cent of the holding power of the vise itself. Parallels, V blocks, and swiveling V blocks are made commercially. (See Fig. 302.)

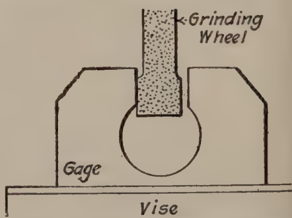


FIG. 303.—Shows a wheel relieved on the sides for "face grinding a snap gauge."

Surface grinding calls for patience; it cannot be rushed, or heat will be generated on one side and warp the work. One or two thousandths chip with $\frac{1}{16}$-in. feed may be all a thin piece will stand unless provision is made for a flow of water on the work. The wheel should be softer than for the same material in round work because the wheel contact is greater.

When grinding a shoulder or facing, especially in the surface-grinding machine (see Fig. 303, for example) care must be taken to note that there is no end play in the machine spindle and that the bearings are well oiled.

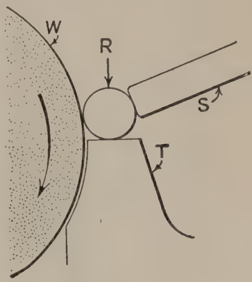


FIG. 304.

339. The Centerless Grinding Machine.—It is the purpose of this text to treat of the first principles of machine-tool operation and to mention only occasionally production machines and methods. The centerless grinding machine (Fig. 306) is primarily, but not essentially, a production machine. It is one of the most interesting and valuable developments in grinding practice. It serves here to illustrate the importance of simple fundamental principles. The machine itself is not complicated, the levers are few and conveniently arranged; most anyone can run the centerless grinder, but *especially valuable* is the operator of any grinding machine who understands grinding wheels, wheel speeds, and work speeds, feeds, and depths of cut, in their relation to the job and to each other.

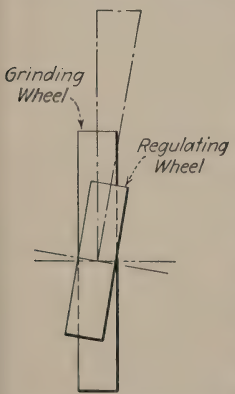


FIG. 305.—Swiveling of regulating wheel to feed the work.

340. Features of the Centerless Grinding Machine.—If, in any wet tool grinder, Blount, for example, a rod R (Fig. 304) is supported by the tool rest T and lightly pressed against the revolving wheel W with a stick S, the rod will be ground fairly round. If, instead of the stick, a set wheel, slowly revolving, regulated the *rotation* of the rod, and, together with the support, controlled the *position* of the rod with reference to the grinding wheel, the rod would be ground almost exactly round. If, further, the regulating wheel were swiveled (tilted) a little (Fig. 305), it would have a tendency to "feed" the work lengthwise and thus grind the whole length of the rod as it passed between the wheels.

By developing these ideas, the centerless grinding machine (Fig. 306) has been designed for grinding cylinders, tapers, shouldered pieces, spheres, and even irregular-profile surfaces, with the highest degree of commercial-grinding accuracy, and

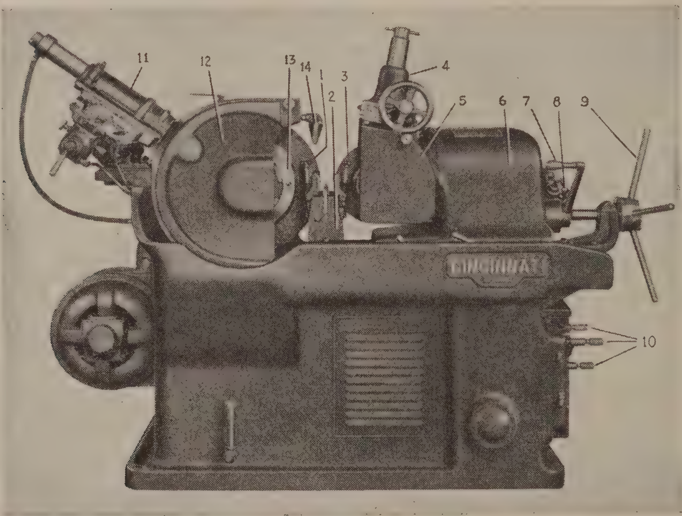


FIG. 306.—Centerless grinding machine. (*Courtesy of Cincinnati Milling Machine and Cincinnati Grinders Incorporated.*)

PART NAMES

1. Grinding wheel.
2. Work rest, holds the work-support blade and four adjustable work guides.
3. Regulating wheel.
4. Screw-type truing and dressing device for the regulating wheel.
5. Regulating-wheel housing. The whole housing, including the regulating wheel (3) and the truing device (4), may be swivelled as a unit.
6. Upper slide, carries the regulating-wheel housing (5). The lower slide (not visible) carries the work rest (2).
7. Infeed lever. A down movement of 90 deg. moves the infeed unit forward 0.038 in. (The infeed unit comprises all parts (2) to (8) inclusive.)
8. Micrometer infeed device.
9. Pilot wheel for adjusting the housing slides (6) which carry the regulating wheel and the work rest. The work rest is, itself, adjustable on the lower slide (not visible).
10. Speed-change levers for twelve speeds of regulating wheel.
11. Hydraulic truing and dressing unit for grinding wheel.
12. Grinding-wheel guard. This and the regulating-wheel guard are easily removable to change the wheel mount and wheel.
13. Grinding-wheel mount.
14. Coolant pipe. Large coolant tank is in rear of machine.

often at a considerable increase in production over other methods.

There are two primary methods of grinding the work in this machine. One is the through-feed method in which the work passes axially from one side of the machine to the other,

entering a rough blank and coming out a semifinished or finished product. This is for straight cylindrical work. In the case of taper, shoulder, or form work, the infeed method is used. This consists of entering the work either laterally or vertically into the grinding throat between the grinding and regulating wheels, steadying it in this position during the operation, and then ejecting it from the grinding throat.

The grinding wheel (1) serves solely for grinding purposes, while the regulating wheel (3) controls the speed of rotation of the work, as well as the longitudinal feeding movement. Angular adjustment of the regulating wheel makes it possible to vary the feed of the work through the machine without changing the speed of work rotation. In combination with a device which automatically supplies and ejects the work, to and from the grinding position, this makes the grinding cycle almost completely automatic.

The work rest (2) is mounted on an adjustable slide and may be correctly positioned with reference to the grinding and regulating wheels to take care of various diameters of work. It consists of a substantial cast-iron block, which holds the work-support blade and four adjustable work guides.

To accommodate various sizes of work, and for accurately sizing any given diameter, the regulating wheel has lateral adjustment: rapid with the pilot wheel (9), and a very fine hand adjustment (8) with a dial reading tenths of thousandths of an inch. In addition, a quick-acting lever (7) and positive stop are provided for infeed grinding.

The regulating wheel is carried in a housing (5) which may be swiveled about a horizontal axis and clamped in the desired position. This is to provide for different rates of longitudinal feed. There are 12 changes of speeds of the regulating wheel, obtained through sliding gears by positioning the levers (10). When through-feed grinding, the speed of the regulating wheel determines the work speed, and the inclination (tilting) of this wheel determines the rate of feed.

There is a proper ratio of grinding-wheel speed and work speed, and a proper feed, for every grinding job. The adjusting fea-

tures and the speed changes of the regulating wheel provide the necessary flexibility closely to approximate ideal conditions.

Standard wheels for the machine illustrated are: grinding wheel, 20-in. diameter, 4-in. face; regulating wheel, 12-in. diameter, 4-in. face. Each wheel has its own truing and dressing device, hydraulic (11) for the grinding wheel, and screw type (4) for the regulating wheel. The careful dressing of the wheels is always important, and these devices are precision made.

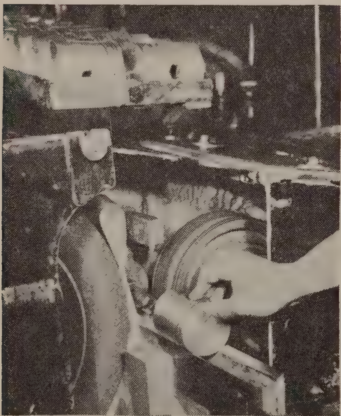


FIG. 307.—Centerless grinding.

341. Laps and Lapping.—Lapping is the process of giving extra smoothness and accuracy to a hardened and ground piece. The lap is a piece of comparatively soft material, such as lead, copper, brass, or gray cast iron, into which the abrasive grains are "charged," that is, imbedded in the lap, by rubbing or rolling. In general, the harder lap cuts slower but gives greater accuracy.

Laps are made *flat*, as a lapping plate, which is merely a flat cast-iron plate of suitable size; cylindrical for *internal* lapping (Fig. 308), and with a straight hole for *external* lapping (Fig. 309).[1]

[1] A machine-steel disk or "wheel," charged with diamond dust, may be used to finish very small holes or formed shapes where a grinding wheel would not hold its shape. This disk is often called a "diamond lap." When run at about two thirds of grinding-wheel speed, it will give an excellent finish and will hold its cutting qualities.

Commercial cylindrical gauges and similar jobs, where the number will justify the setup, may be lapped on centers in a grinding machine. An aluminum disk is used in place of the grinding wheel. The aluminum is itself an abrasive, and the lapping compound consists of powdered aluminum and sperm oil. The wheel does not load. For a finish that approaches lapping, fine-grain close-structure aluminum-oxide wheels may be used.

There are several ways of making internal laps, three of which are shown in Fig. 308. The lap *a* is split practically its full length and may have one or more screws for spreading. To make the lap *b*, a tap-size hole is drilled about half the length and then a smaller hole for a short distance further. The hole is tapped a few threads and fitted with a pointed screw. The lap is split the same as *a*. The pointed screw serves to spread the lap. A lead lap *c* is poured, somewhat oversize, around a taper mandrel which has a lengthwise groove. The lead in the groove acts as a key. After the lead is turned to size, it is split along one side.

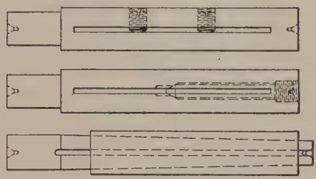


Fig. 308.—Internal laps.

The purpose of the lap is to give a smoother, more accurate and longer wearing surface by removing usually from 0.00025 to 0.0005 in. from a carefully ground piece. Abrasives from No. 120 to the fine powders are used, depending upon the job. Also there are special lapping compounds made by abrasive manufacturers. Silicon-carbide abrasive cuts faster; aluminum oxide gives a better finish. Lapping is precision work. This means the use of a well made lap, carefully charged, and used with constant attention and care.

When lapping a bushing or a similar piece, the lap should be at least twice as long as the hole and must fill the hole with a wringing fit. The speed of the lap should be fairly slow, say, 250 r.p.m. for a 1-in. diameter. For lead laps even slower speeds are recommended. Hold the work by hand; if ever permissible to hold it otherwise, be careful not to squeeze it out of round. Feed the work back and forth along the lap, and when it seems a trifle free apply more abrasive. To avoid bell-mouth holes (larger on the ends), put the abrasive and the lubricant in the slot along the central part of the lap; this will serve to distribute the abrasive from the center as the work is moved back and forth. Keep the lap well charged, but without excess abrasive. Keep the wringing fit; if the

lap is too free after charging, it must be expanded. One soon recognizes the proper cutting action by the *feel.* Clean and cool the work in a gasoline bath at room temperature before gauging.

What is stated above applies as well to lapping a cylindrical piece. The external lap is made as illustrated in Fig. 309, usually of cast iron. It should have both closing and spreading screws. This form of lap is often made with renewable split bushings of brass, copper, or cast iron.

In the figure, *a* shows a cast-iron lap with spreading screw *S* and tightening screw *T*. In *b* is shown the same type of lap provided with a renewable split bushing *B* kept from turning by the screw *A*.

When using any kind of lap, be sure the machine parts, the chuck, etc., are protected from scattered abrasive.

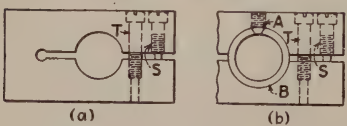


FIG. 309.—External laps.

A lap for flat surfaces, such as size blocks, gauge parts, etc., is a seasoned and finished cast-iron plate with a flat surface, say 6 or 8 in. square, charged with fine or "flour" abrasive and gasoline, or an equivalent lapping compound. To insure a flat-lapped surface the work is given a back and forth and circular motion over practically the whole surface of the plate, and is occasionally allowed to twist around under the finger pressure. The plate is cleaned with gasoline as often as it becomes sticky. To give the "finishing touch" to the work, wipe the plate dry and clean, and then lap dry or with kerosene, as preferred. The clean plate will be sufficiently charged to give the finish desired.

Questions on Grinding, II

1. Can you suggest why a wheel that has been running a few minutes will run smoother and in a slightly different position than when first started?

2. Are you able to tell a sound wheel from a cracked wheel?

3. Make notes of your moves in grinding a cylinder and compare with paragraph 330.

4. Set down the operations in grinding a taper. How do these operations compare with those for grinding a cylinder?

5. What very important precaution must be observed when grinding tapers to size if the automatic cross-feed and stop are used?

6. If, when setting up for grinding tapers, the first piece is getting near to *size*, but not quite the right *taper*, why is it advisable to take that piece out and start another?

7. If the piece being ground has, for example, a 6-in. taper per foot and does not go far enough in the gauge by ¼ in., how much too large is it?

8. What precaution is necessary when grinding shouldered pieces?

9. Suppose you had to grind a dozen shouldered jig bushings similar to *b*, Fig. 39 (page 39), would you set the reversing dogs? Would you use the automatic cross-feed?

10. State how you would grind these bushings and why.

11. When grinding an angle by swiveling the wheelhead, how is the wheel fed *along* the work?

12. As in above question—how do you feed to take a deeper cut?

13. As in questions 11 and 12—can either automatic feed be used? Explain.

14. Swiveling the wheelhead 45 deg. will grind the work 45 deg. with its center line. Will swiveling the table 30 deg. grind the work 30 deg. with its center line? Make a sketch and explain this.

15. How may you regrind the centers of the machine if necessary? Could you hold work in the chuck on the headstock spindle and grind an angle?

16. What is the "face chuck?" What is the purpose of the expansion bushing? How is it expanded?

17. How would you set up to grind a slotting cutter for the milling machine to have it slightly thinner toward the center for clearance?

18. Are you able to set up the internal-grinding attachment?

19. What is a bell-mouthed hole? How do you account for a bell mouth?

20. State two methods of setting up to grind a taper hole.

21. Suppose a piece is clamped too hard or otherwise strained. Is it true when the pressure is released? Explain.

22. What is a magnetic vise?

23. Is a piece 6 in. square more securely held in a magnetic vise than a piece 1 in. square? How are the small pieces kept from slipping?

24. Of what use is an angle plate on a magnetic vise?

HYDRAULICS

CHAPTER XVII

HYDRAULIC POWER TRANSMISSION

342. Introduction.—The application and design of hydraulically (oil) controlled machine-tool driving and feeding mechanisms is engineering rather than machine-shop practice. Nevertheless, the machinist should have an interest in the features that account for the importance hydraulics now occupies in machine-shop practice, especially in reciprocating-table and slide movements and speed and feed controls, as he must certainly be able to build, operate, adjust, and repair these machines.

The purpose of this chapter is to discuss, briefly, the first principles of the use of oil under pressure to give the power when and where needed in the movement of a machine part. Since the hydraulic units and "circuits" are well developed as to purposes and methods, only a general survey of fundamentals is necessary to open the way to a study of the particular pump, valve, or cylinder, or the machine in which these units are used.

Usually when thinking of hydraulics, it is in terms of water falling from a higher level, in which pressure is the *head* and volume is, of course, the rate of flow. In the hydraulically (oil) operated machine, this head (pressure) and volume are regulated by a pump, together with certain valves.

Hydraulically operated mechanisms, embodying Pascal's law—that *pressure applied to a fluid in a pipe or other enclosed container, is transmitted equally in all directions, to every part of the fluid and every surface it reaches*—have been used for many years. Hydraulic presses and elevators are examples. More recently, many applications of this easily controlled steady flow of power (the pressure of oil, forced by a pump) have been found efficient in production machines, such as

broaching, grinding, and milling machines; and the hydraulic shaper, planer, and grinding machine now have a place in the general machine-shop and toolmaking departments.

In Fig. 310 are two diagrams showing the flow of oil in a simple hydraulic circuit containing a motor-driven *pump*, a *relief valve* to protect the system against excessive pressure build-up, a *directional control valve* for reversing the flow of oil to the cylinder, and the *cylinder* with the piston and piston rod (or cylinder rod). In the diagram *a*, the arrows trace the flow of oil forcing the piston and rod to the left, and in *b* the direction is reversed. Note the three positions of the

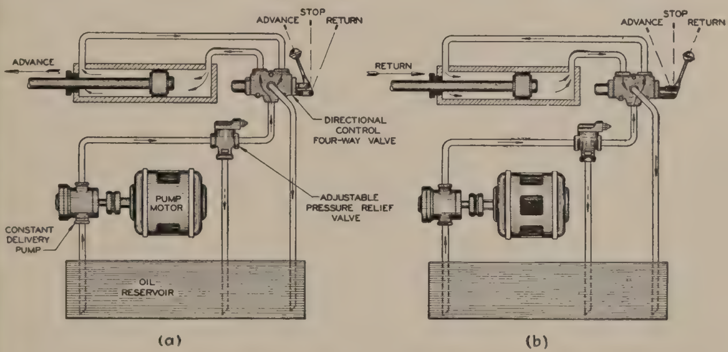


FIG. 310.—Simple hydraulic circuit. (*Courtesy of Vickers Incorporated.*)

control-valve handle; when in middle (stop) position, the oil flows to the valve, through an "open center" or "by-pass" of the valve plunger, and back to the reservoir. There is no pressure on either side of the piston, and the piston (and machine table) stops. The pump keeps on running but under no appreciable load.

It is the development of the various kinds of pumps, valves, cylinders, and other mechanical devices, the principles of which are described in this chapter, that is responsible for the advantages, and the consequent increasing use, of hydraulics in machine tools.

343. Advantages of Hydraulic Power Transmission.—1. The easy control of the force, that is, of the rate of flow, or pressure, or both, that may be applied.

2. Even, positive motion at all loads.

3. The accurate and convenient controls themselves—the valves by means of which a variety of motions such as table drive, feeds, inching, and clamping may be obtained, often in a cycle automatically.

4. The range of stepless speeds and feeds from zero to maximum, any one obtainable almost instantly without stopping the machine.

5. The cutting speeds and feeds are independent of each other and may be adjusted to meet the requirements of each.

6. Remarkably smooth, steady cutting action, no gear marks or chatter; tools last longer.

7. The cutting speed and power, in the shaper and planer, for example, reaches maximum almost instantly and remains constant during the whole stroke.

8. The rapid reversals at each end of the reciprocating stroke, of a surface grinder, for example, are *cushioned*, that is, they are especially smooth and shockless. This cushioning effect may be increased if advisable by the addition of a dashpot.

9. Dwell at the end of the feed may be provided to work automatically. This feature is often desirable when finish milling to a filleted corner, spot facing, etc.

10. Direct application of the power is provided. In the planer, for example, the hydraulic cylinder is close up under the platen.

11. Lubrication of all parts is inherent in the unit.

12. The flexibility, as evidenced in the number and variety of motions—for locating, clamping, driving, feeding, etc.—that may be employed in a single machine. And in the use of the *unit idea* in construction, which permits of easily made changes at comparatively low cost when, for example, improved machining conditions might warrant a different valve or pump, or possibly an extra pump. Also in the commercial units themselves—many sizes, readily obtainable, all designed for compactness, durability, efficiency, and for con-

venient location and assembly with respect to the other machine units.

344. Hydraulic Units.—There has been, in the last few years, a great advance in the manufacture of hydraulic driving and driven units, and in valves and other devices for power and speed control. High-pressure pumps of both *constant displacement* (uniform rate of flow) and *variable displacement* (adjustable rate of flow), and of both in one unit, are commercially available. This is true also of the kinds and sizes of valves for controlling the oil pressure, and the amount and direction of flow. Also the rotary motors (driven) and the reciprocating (piston and cylinder) types of driven units, and all necessary pipes and fittings, are standard equipment. That is, the manufacturers supply any or all of these, and, as units, they may be built into machines made anywhere.

345. Pumps.—The pump, run at constant speed, usually by an electric motor, takes the oil from the supply reservoir and delivers it at sufficient volume and pressure to do the work required. Three types, the gear pump, the vane pump, and the plunger pump, are shown in Figs. 311, 312, and 314, respectively. The gear and vane types shown are constant-delivery pumps, and the plunger pump is of the variable-delivery type.

There are many modifications of these types of pumps built by the different makers, and each is made in a variety of sizes. The gear pump is probably the simplest kind of commercial medium-pressure constant-delivery pump. The vane type has advantages in size, weight, quiet running, and long life and is highly efficient. The plunger type lends itself readily to variable delivery, high pressure, and smooth flow, and alone or together with a constant-delivery unit, is an important factor in many hydraulic applications.

A constant-displacement pump is, theoretically, run at a speed that will give the volume and pressure desired. Ordinarily, however, it is speeded for a somewhat greater output, and a relief valve, set at approximately the pressure needed in the machine operation, is used to take care of the extra flow,

if any. To give the slower speeds of the driven unit the oil must be throttled, and more oil will go through the relief valve. This is an objection if much changing of speeds is necessary as it consumes power and generates heat in the oil.

The variable-displacement pump runs at a constant speed, but it may be adjusted to deliver more or less oil, so that just enough pressure is imparted to just enough oil to do the work required. Theoretically no energy is put into the oil except that which will be used in doing the work, plus the friction loss and a trifle of leakage ("slip").

The variable-displacement pump has its advantages for heavy duty and variable duty and is widely used. The vane-type and gear-type constant-displacement pumps are lower in cost, simpler in construction, and, used with modern valves, are favored for machines not requiring excessive power or wide variation in speeds.

346. The Gear Pump.—This type of pump, shown in Fig. 311, has been in use for many years for raising and circulating (pumping) various kinds of liquids. Its wide use in the hydraulic transmission of power is due to (1) the large volume at medium pressure of which it is capable; (2) its quiet running at high speed, owing to ball bearings, helical gears, etc.; (3) its simplicity, low first cost and upkeep; and (4) its small dimensions.

In action the two gears in mesh, revolving in the direction shown in *b* (Fig. 311) tends to create a vacuum in the inlet chamber *A*. The atmospheric pressure in the oil reservoir forces the oil to fill this suction chamber, and the oil is engaged by the teeth of the gears and confined in the spaces *B* until released and is then expelled through the outlet. The pressure given to the oil by the pump depends primarily upon the speed of the gears.

347. The Vane Pump.—A vane pump is illustrated in Fig. 312; the diagrammatic section (Fig. 313) illustrates the operation of this pump. The particular type indicated is termed "hydraulically balanced" for the reason that there are two diametrically opposing pumping chambers which, being

opposite each other, cancel out thrust forces imposed by the pumping action. Were these forces not balanced, they would cause heavy bearing loads while the pump is developing high operating pressures.

When the pump is in operation, the bladelike vanes slide radially inward and outward in slots while being carried around by the rotating vane carrier or *rotor*. Power from the pump-driving motor is transmitted through the pump shaft to the rotor by a floating spline, the shaft and rotor being supported on separate bearings.

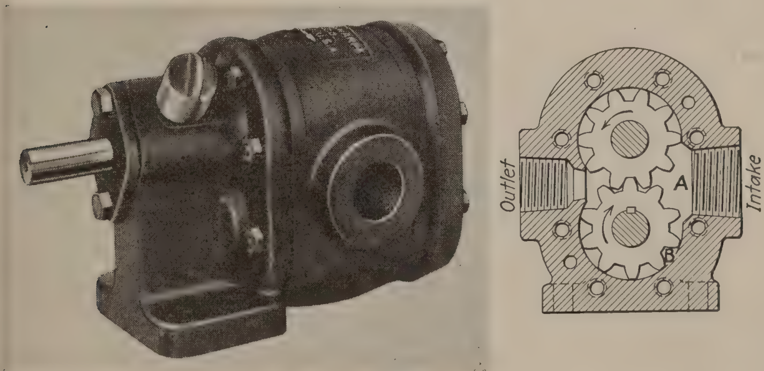


FIG. 311.—Gear pump. (*Courtesy of Brown & Sharpe Manufacturing Company.*)

It will be noted that the radial sliding motion of the vanes is controlled by the internal camlike contour of a hardened guide ring. This ring also forms the outer circumferential wall of the oil chamber. The contour is ground to a shape which causes the vanes to move radially outward and back toward the center twice during each revolution of the rotor. Centrifugal force, plus pressure from an exhaust-port bleed, insure that the vanes follow the cam-ring contour at all times.

The inlet and discharge ports are located in the parts which form the *sides* of the pumping chamber. They are indicated in Fig. 313 as A, A_1, and B, B_1. The functioning parts described, including the hardened guide ring, are assembled

within a pump casing, this casing containing the inlet and outlet piping connections and the passages leading from these to the port openings.

It will be noted that port A is directly opposite A_1, and B opposite B_1. The rotor is shown in this instance revolving counterclockwise, with vane 1 about halfway across port A, traveling to the left. A suction is being created in the oil-chamber space between vane 2 and vane 1, and also behind vane 1, owing to the enlargement of these spaces as the rotation progresses, and oil from the supply reservoir is therefore forced into the chamber through the inlet by atmospheric

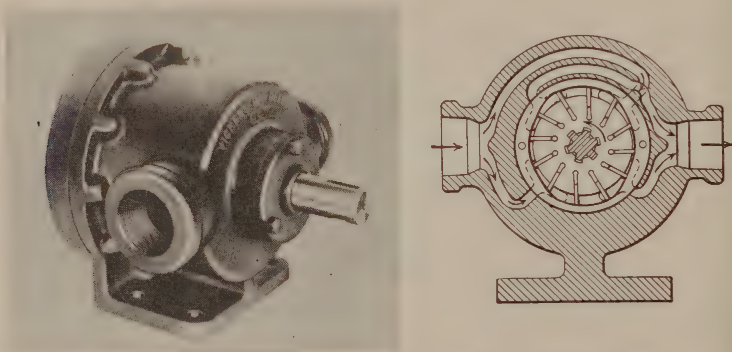


FIG. 312.—Vane pump. (*Courtesy of Vickers Incorporated.*)

pressure. Conversely, oil previously trapped ahead of vane 2, as well as that ahead of vane 3, is being forced out through exhaust port B. This port leads to the pressure, or outlet, connection of the pump. At the same time, the opposite pumping chamber is functioning in like manner—intake through A_1, outlet through B_1. Since developed pressures and vacuums are equal at all times in opposing chambers, there is no crowding effect or load on the rotor bearings because the forces cancel each other.

The guide ring is so designed that radial vane movement takes place only when the vane is opposite one of the four port openings. This fact is important in that a cantilever load caused by a higher pressure in front of a vane than behind it

cannot be imposed upon a vane at any time during which it must slide in its rotor slot. However, such a cantilever condition does exist on a vane while it travels between port openings, owing to the outlet pressure being imposed on the forward side of the extended portion of the vane while a sub-

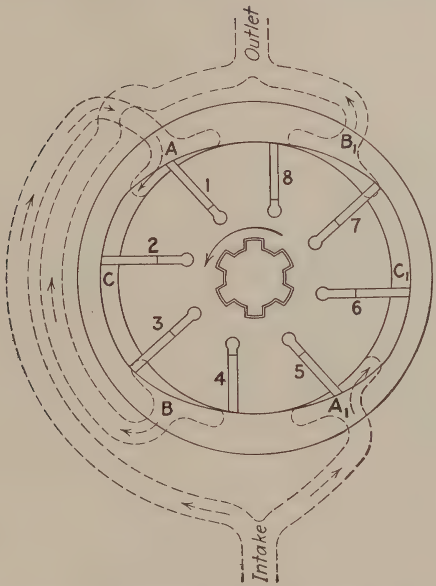
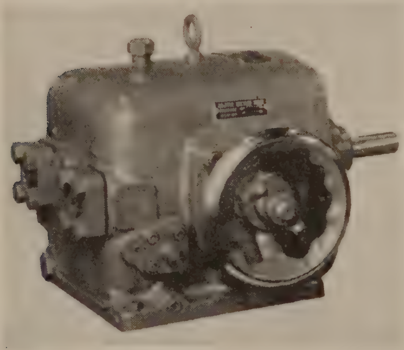


FIG. 313.—Explanatory diagram of pump shown in Fig. 312. Vane 1 is about halfway across the port A thus gathering a certain amount of oil. Vane 2 is forcing the oil it has gathered through the true arc enclosure C. Vane 3 is just starting to force the oil through outlet (pressure) port B. Vane 4 has finished forcing its volume of oil through port B, and not yet started to gather oil from A_1. Note the balancing effect of the vanes 5, 6, 7, and 8 and ports A_1 and B_1 with vanes 1, 2, 3, and 4 and ports A and B.

atmospheric inlet pressure exists on the rear side. Therefore the shape of the guide ring between the ports is ground to a true arc of a circle having its center on the center line of the shaft, thus assuring that there will be no radial motion of the vane in the slot while the cantilever condition is existent. Summarizing, no vane load is imposed while radial motion occurs, and no radial motion takes place while the vane load is present.

When high operating pressures are encountered, such as those for which this type of pump is designed, these points of "hydraulic balance," etc., are important in assuring quiet running and long operating life.

348. The Plunger Pump.—In the plunger type of pump (Fig. 314) the piston, or *plunger*, which fits closely in its cylinder, draws in the oil as it moves outward, and expels the oil as it is pushed back. These pumps have five or more radial cylinders, each, of course, with its plunger.



(*a*)

(*b*)

FIG. 314.—Variable-displacement pump; (*b*) section view of the plunger pump contained in this unit. The position of the slide block (2, Fig. 315) to give greater or less flow of oil is adjusted by turning the hand-wheel shown in (*a*). (*Courtesy of The Oilgear Company.*)

Referring to Fig. 315 which is an explanatory diagram of the pump shown in Fig. 314: First, the pintle (6), which is a sort of stud shaft with oil ports and passages, is *fixed*, that is, it does not revolve, nor is its position changed at any time. Second, the cylinder barrel (5) carries in its radial cylinder bores the plunger-pistons A, B, C, D, and E. It rotates on the pintle (6) and therefore is not adjustable. Third, the plunger heads work against the reaction ring (4) which is carried by the rotor (3), and the ring and rotor will therefore rotate with the cylinder barrel (5). Fourth, the rotor (3) and the ring (4) are carried in the adjustable slide block (2) and therefore may be adjusted off the center of rotation of the cylinder barrel by an amount equal to the distance X. Fifth, since the

plungers are kept always against the reaction ring (4), and the rotation of the cylinder barrel (5) is out of center of the rotating reaction ring, the plungers will be given a reciprocating movement in their cylinders. (Note plunger *E* pushed *in*, and plunger *B* pulling *outward*, in their respective cylinders.) Sixth, the pintle has two lengthwise oil passages, one (7) acting as intake or suction port, and the other (8) as the outlet or

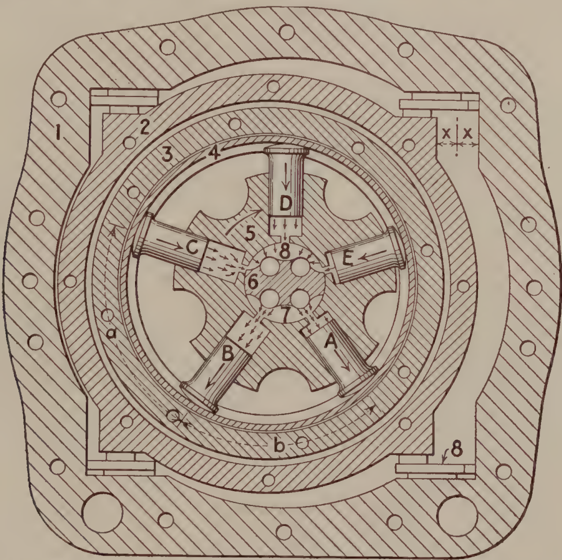


FIG. 315.—Explanatory diagram of plunger pump shown in Fig. 314. 1. Casing. 2. Adjustable slide block. 3. Rotor. 4. Reaction ring. 5. Cylinder barrell. 6. Pintle. 7. Intake port. 8. Pressure port. *A*, *B*, *C*, *D*, and *E* are plungers. The *reaction* ring (4) both *pushes* and *pulls* the plungers.

pressure port. Seventh, the piston *C*, which has been pulled outward and has filled its cylinder with oil, has just started to push the oil from its cylinder into the outlet port (8), and the piston *A* is well started in drawing the oil from the suction port (7).

In action, the pump shaft is driven clockwise at constant speed. This rotation is transmitted through a suitable coupling to the cylinder barrel (5) mounted on the pintle (6). The plungers in the rotating cylinder barrel (5) are confined in

the rotor (3) by the reaction ring (4), while the rotor is carried on antifriction bearings in the adjustable slide block (2), and the *eccentric relation* of the rotor and the cylinder barrel (with the rotor and ring holding the plunger heads, and the cylinder barrel containing the plungers) causes a reciprocating movement of the plungers.

When the center lines of the rotor and the cylinder barrel coincide, there is no reciprocating movement of the plungers, and no oil is pumped. As the slide block (2) with the rotor (3) and the ring (4) are moved to the left, as shown in Fig. 315, their centers no longer coincide and a reciprocating movement is imparted to the plungers, and those passing over the port (8) are delivering oil, while those passing over port (7) are drawing oil. Since the slide block (2) is adjustable, the amount of reciprocating movement of the plungers is variable from zero to maximum. This means that the flow of oil may be varied from zero to maximum. Also, by moving the slide block to bring the rotor to the other side of center, the flow of oil from the pump may be reversed. The port (7) then becomes the pressure port, and port (8) becomes the intake port.

The "creep" of the plunger-heads on the ring, caused by the constantly changing arc distances between the plunger-heads (see *a* and *b*, Fig. 315) is adjusted (compensated) by a slow movement of the convex plunger head on the surface of the ring, which gives a slight rolling of the plunger in the cylinder, in one direction during half its whirl around the pintle, and in the other direction during the other half.

349. The Value of the Variable-displacement (-delivery) Pump.—This pump, one kind of which is shown in Fig. 314, is used where the rate of flow must change considerably for various speeds of the driven unit, or where, as in a milling machine, a closely measured flow for accurate feeding operations is necessary. Also, in such machines as the shaper and planer, it is valuable not only for obtaining better cutting conditions, but it quickly accelerates the inertia load and gives full power for practically the whole length of the stroke, smoothly, steplessly, without wear and tear.

In certain installations the variable-delivery pump may be equipped with a control which will automatically keep the pressure constant, thus compensating for variable feeds, and even for the stalling of the driven unit.

In many machine-tool hydraulic applications the constant-delivery pump is used in conjunction with the variable-delivery pump in one unit or in separate units. There may be one high-pressure, low-volume variable-delivery pump to feed the machine against the cutting tool rather slowly but with con-

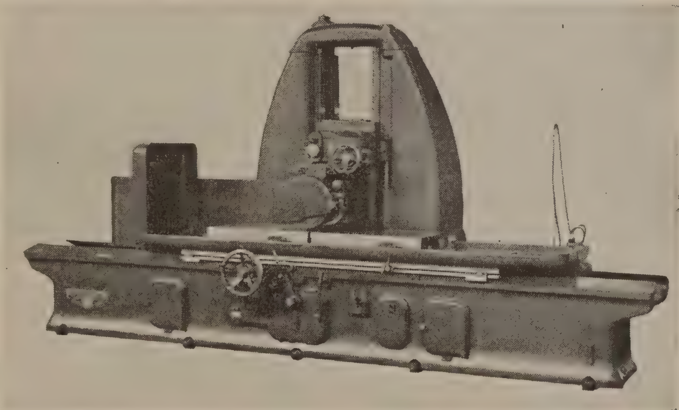


FIG. 316.—High-duty precision surface-grinding machine. For this machine Oilgear hydraulic units (pump shown in Fig. 314) provide smooth positive travel of the table at speeds from 30 to 100 ft. per min.; quick, cushioned table reversal; inching of table; automatic feed and rapid cross traverse of grinding wheel. (*Courtesy of Mattison Machine Works.*)

siderable pressure, and the other low-pressure high-volume pump to run the table rapidly back to the beginning of the cut (rapid reverse). The rapid reverse needs plenty of oil (large volume) to push the table faster, but high pressure is not required, since there is no feeding pressure.

In Fig. 314 is illustrated a unit which comprises both types, plunger type (variable delivery) and gear type (constant delivery) together with the necessary control valves. Such a unit is used in the machine illustrated in Fig. 316.

A similar unit has proved successful on production milling machines. It provides rapid traverse, either direction, and

one or two adjustable feeding speeds in one direction or both directions.

In such a unit, of a size to be driven by a 5-hp. motor, the multiple-plunger variable-displacement pump delivers from 10 to 350 cu. in. per min. at a maximum pressure of 1,000 lb. per sq. in. The gear pump has a capacity of 8,000 cu. in. per min. constant volume at 300 lb. per sq. in. working pressure.

The variable-delivery pump may be used to give pressure, as against a piston in a driven unit, or as a *meter* (measure) to limit the rate of flow of the oil, as from the delivery end of a cylinder. In the meter application, in a milling machine for example, the power unit may contain a variable-displacement pump and two other pumps, one to supply the oil that actually pushes the piston as fast as the metering pump will allow it to go, and the other for the rapid reverse. The "back pressure" of the metering pump holds the feed remarkably steady and prevents any lunging at a light cut or at the end of a cut. It is of particular value when advisable to feed *with* the direction of the cutter instead of *against* it (see page 245).

NOTE.—In the diagram (Fig. 329, page 434) is shown a double vane pump which, through its automatic control, serves to supply the volume and pressure needed for the cycle of rapid advance, feed, and rapid return. In this system the back pressure is regulated by the valve *G*.

350. Valves.—The purpose of the valves is to control the flow of oil. The flow is through passages called *ports;* in through the *suction* (intake or inlet) port; out through the *pressure* (outlet) port.

Valves may be operated mechanically, electrically, or hydraulically, and for most actions may be automatic. Very sensitive valves for controlling the slightest movement ("inching"), even 0.001 in. of heavy tables, are not uncommon. Frequently two or more, and quite often several, valves are incorporated in the same hydraulic system.

A pilot valve is operated usually by dogs on a sliding table (or by hand) to release a comparatively small amount of oil to actuate some larger valve. A relief valve may be adjusted to

open at a predetermined pressure. A check valve permits a one-way flow only. A reverse valve is for the purpose of changing the direction of the flow of oil to the driven unit. A resistance valve (foot valve) offers resistance in one direction of the flow. A *control* valve may cover a variety of uses, as starting, stopping, speed changing, and quite often the movement of other valves for various purposes.

351. Piston-type Valves.—Most valves in hydraulically operated machines are of the plunger or piston type, as shown in Figs. 317 and 318. A given port is closed, that is the oil is shut off from entering that port, by the "land" of the plunger, and the connection (opening) between adjacent

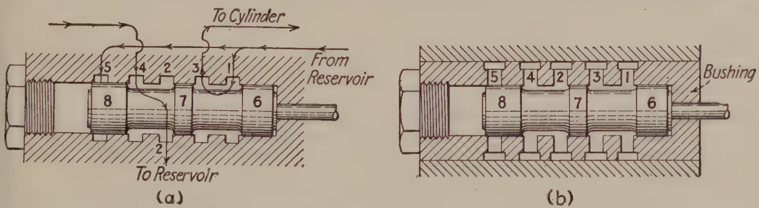


FIG. 317.—In (*a*) the inside grooves or recesses in the valve chamber are numbered 1 to 5; the "lands" on the valve plunger are 6, 7 and 8, with the "spools" between. In (*b*) are shown the radial holes 1 to 5 and the connecting grooves in the *bushing* that, in this construction, forms the valve chamber. In either (*a*) or (*b*) the connecting oil pipe may enter the given groove at any point.

ports is made by the spaces or "spools" between the lands. The ports are either annular grooves (recesses) bored or cored in the surrounding valve chamber, as shown in *a*, Fig. 317, or radial holes drilled in from grooves turned in a surrounding bushing, as in *b*, Fig. 317. To have the valve work freely it is necessary to have the oil pressure even (balanced), and this is the case with plunger-type valves.

The diagram (Fig. 318) illustrates in a simple manner how the piston valve works; arrow lines are drawn to represent the flow of oil through the pipes, ports, valve chamber, etc. Referring to *a*, the oil from the reservoir, under pressure of the pump, is forced through an opening (1), in the valve chamber to any part—top, side, or bottom, as the case may be—of the annular groove across the space (spool) to (3), thence

piped to the right-hand end of the cylinder and piston of the driven unit. Meanwhile the oil from the other side of the piston is being returned to the reservoir. It is forced by the pressure on the right side of the piston *from* the cylinder through a pipe to (4) thence to the reservoir.

Now refer to *b*, Fig. 318. As the valve plunger is instantly changed (say, by the action of the dog on the machine table) to the position shown in *b*, the oil flow is reversed. The oil from the reservoir is now forced through (1), then across to (4), and from there it is piped to the opposite (left-hand) end of the cylinder, and the oil on the other side of the piston is returned through the pipe to (3), across the space to (2), and thence to the reservoir.

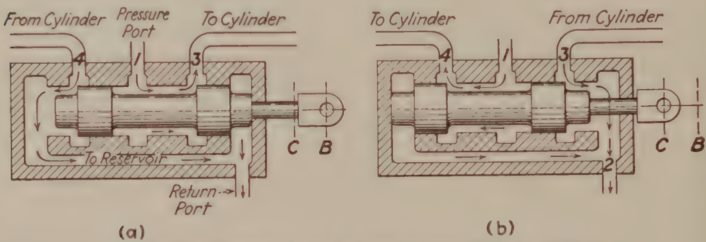


FIG. 318.—Diagram of a piston-type reverse valve.

352. The Control Valve.—The purpose of the pump is, of course, to give pressure to the oil; in other words, to give power to the machine. The purpose of the valves is to control the flow of oil and to apply the power when and where needed. To illustrate as simply as possible how this is accomplished in a "circuit," that is, in the run of oil from the reservoir, through the pump, the valves, the driven unit, and back to the reservoir, references are made to the diagrams shown in Figs. 319 and 320.

First get the general idea of the circuit from Fig. 319 (omitting the feeding mechanism), then a clear understanding of the operation of the speed-control and reverse valves (Fig. 320), after which it should not be difficult to understand the details of Fig. 320, including the feed mechanism.

The diagram in Fig. 319 shows the speed-control valve open (speed-control piston pulled out), permitting the exhaust through V port (9) to the reservoir. The machine is running; oil from the reservoir is being pumped in the direction of the arrows through R_1 to the intake port (1) in the valve, out

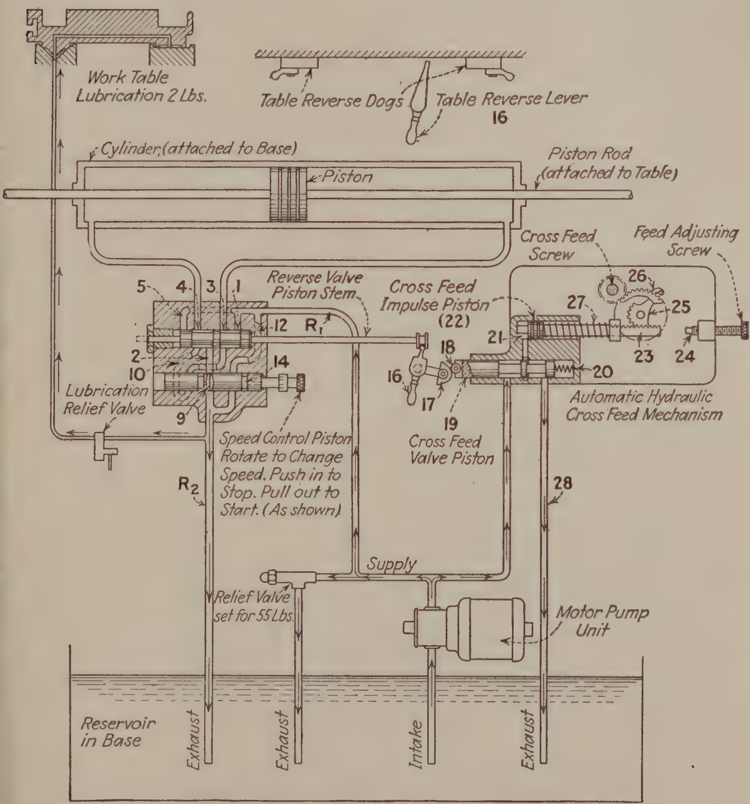


Fig. 319.—Diagram of a typical hydraulic circuit. (*After a diagram from Norton Company.*)

through (3) to the right-hand end of the cylinder, and forces the piston (and worktable) to the left. This pushes the oil on the left-hand side of the piston out of the cylinder and down through (4), across the spool through port (2), and on down through the V port (9) to the reservoir.

The instant the valve is changed, the flow of oil through the valve is reversed (as shown in Fig. 320), and the piston travels in the opposite direction.

Referring to *a* in Fig. 320 (which is an enlargement of the valve in Fig. 319), oil from the reservoir (and pump), through R_1 to (1) to (3) to the cylinder, pushes the piston to the left; oil on the other side of the piston escapes from the cylinder down through (4) to (2) to (9) to R_2 to the reservoir. Notice that the oil can enter (1) but cannot enter (5) because it is stopped by the land (8), also that it cannot enter (10) because it is stopped by the land (11), also that it cannot go through (12) because it is stopped by the land (13).

In *b* (Fig. 320) the valve is shown shifted to the left. This merely closes (1) and opens (5). Oil flows now through R_1 to (5) to (4) to the *left* side of the cylinder, and at the same time the oil on the right side of the cylinder exhausts through (3) to (2) to (9) to R_2 to the reservoir. Note that, as in *a*, the oil can only flow as stated, elsewhere it is shut off by the lands on the valve plunger.

Referring to the speed-control plunger, the V port (9) is simply a notch cut in the side. Rotating the plunger a slight amount serves to reduce the size of the port, and, of course, the amount of oil that can pass through the port, and consequently the speed of the driven piston in the cylinder and therefore of the sliding worktable. When the valve is pushed way in, as in *c* (Fig. 320), no oil is discharged through the V port (9) and the table remains stationary, oil from the pump by-passing through the exhaust line (12) and the space (14). This is the way to stop the table, rather than shutting off (9) entirely, since it avoids forcing the oil through the relief valve.

It will be noted (*c*, Fig. 320) that with the plunger pushed way in and the power traverse stopped, the space (15) in the control plunger opens the line (10), and oil may flow from either end of the cylinder through (10), making hand feed of the table possible. That is, as the table is fed back and forth by hand, the oil which fills the cylinder and pipe line is pushed by the piston back and forth from one side of the piston to the other

through the pipe line. To understand this more easily, refer first to *c* (Fig. 320) and note the line is open through (10) and (15), then refer to *a*, same figure, and imagine this line is open as in *c*. Then as the table is moved from right to left, the oil will flow from the cylinder through (4) to (10) through (15) through the rest of (10) and on up through (3) to the cylinder. When the stroke is reversed and the table

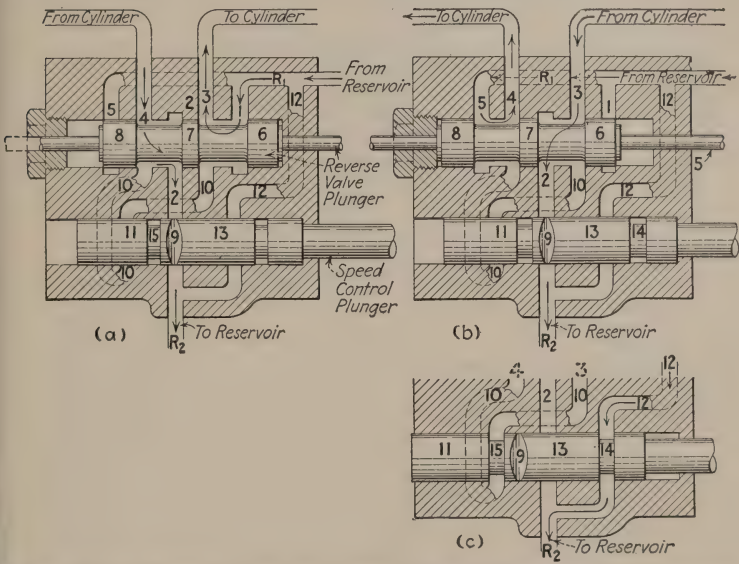


FIG. 320.—Diagram of control valve in Fig. 320 enlarged for clearness. (Actually the *speed-control plunger* is at right angles to the *reverse-valve plunger*, and the port connections, such as (10) for example, are not twisted as they appear here.)

is moved left to right, the oil will be reversed, and will flow from (3) to (10) through the space (15) and up through the rest of (10) to (4), thence to the left end of the cylinder.

353. A Modern Control Valve.—In Fig. 321 is illustrated a modern plunger-type control valve, with drilled flanges, ready to be assembled in the hydraulic system, usually integral with the pump. It is only necessary to install the pipe lines to the one or more cylinders in the system and to connect the valve stem to the control mechanism (operated mechanically

by cam action, or by the ram arm, or electrically by a solenoid, or hydraulically by a pilot valve). In the illustration the port (2) is the exhaust port; the ports (3) and (4) are for connecting

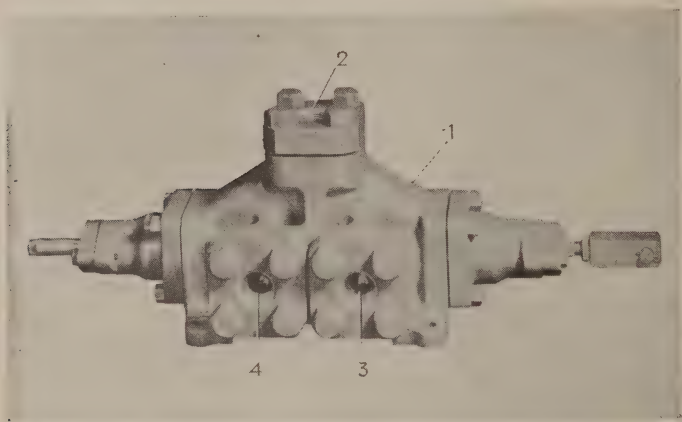


FIG. 321.—Control valve. (1) Intake port is on other side of valve; (2) pressure port; (3) and (4) cylinder ports. For sectional view see Fig. 323. (*Courtesy of The Oilgear Company.*)

to the cylinder or hydraulic motor to be actuated; and the port (1), which is opposite the ports (3) and (4) and not visible, is the intake (pressure) port.

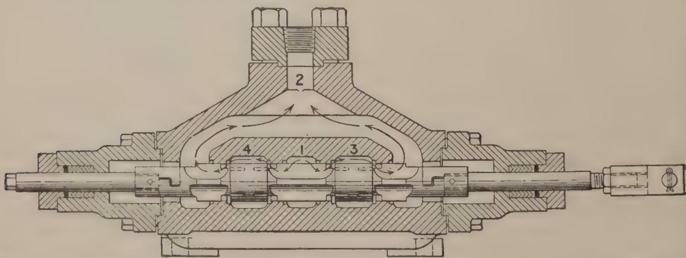


FIG. 322.—Sectional view of four-way by-pass valve shown in Fig. 321. In this view the valve is in neutral position and the oil is by-passing from port (1) to port (2).

The diagram (Fig. 322) is a central cross section of the valve shown in Fig. 321 with a four-way by-pass[1] style of

[1] In a non by-pass form of valve, the valve is either open or closed; in the by-pass valve, one or more ports may be closed, but the plunger is constructed to allow the flow of oil through the valve.

plunger in neutral position. In this plunger the spools or openings for passing the oil are three radially milled grooves, with square-shoulder grooves at the ends. Note the small V grooves cut in the lands to provide a dashpot action when the plunger moves from one position to another.

To serve a particular purpose in a machine, any one of several styles of plungers may be used in a given valve chamber. Some of these styles are diagrammed in Fig. 324. Note that port (2) in the two-way and three-way valves is merely a drain connection to take care of the small amount of leakage (slip) past the plunger. In the four-way valve the port (2) is used also as a return connection from the ports (3) and (4).

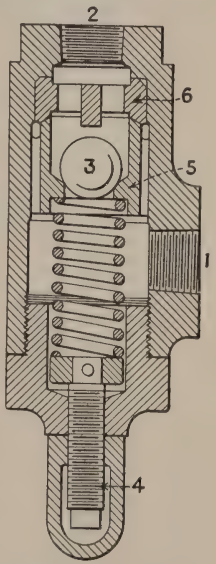


FIG. 323.—Spring-resistance valve or "foot valve." Oil returning through (2) must force (5) downward against the spring and thus make an opening between (5) and (6).

354. The Resistance (Foot) Valve.—In Fig. 323 is shown a section view of an adjustable resistance valve, or foot valve. It is mounted in a vertical position, and the steel ball (3) tends to seal the check by gravity. Oil entering the side connection (1) is free to flow out of the top connection (2) by merely raising the ball (3). Oil flowing in the top connection (2) is restricted by a spring pressure because the ball seats on the check and the entire plunger (5) must be moved against the spring away from its seat (6) in order to have the oil pass. The spring pressure may be adjusted by the screw (4).

In use, the resistance valve may be arranged, one on each end of the hydraulic cylinder, to allow the exhaust to escape freely but offer resistance to the intake. To give an example of the use of such a valve, let it be required to clamp one piece and when it is clamped press another part on it. Two cylinders are used: one, without resistance valves, for clamping, and the other, equipped with resistance valves

for pressing. The connections to the clamping cylinder, having no valve resistance, will allow the flow of oil to complete its function of holding the piece tight before the oil will

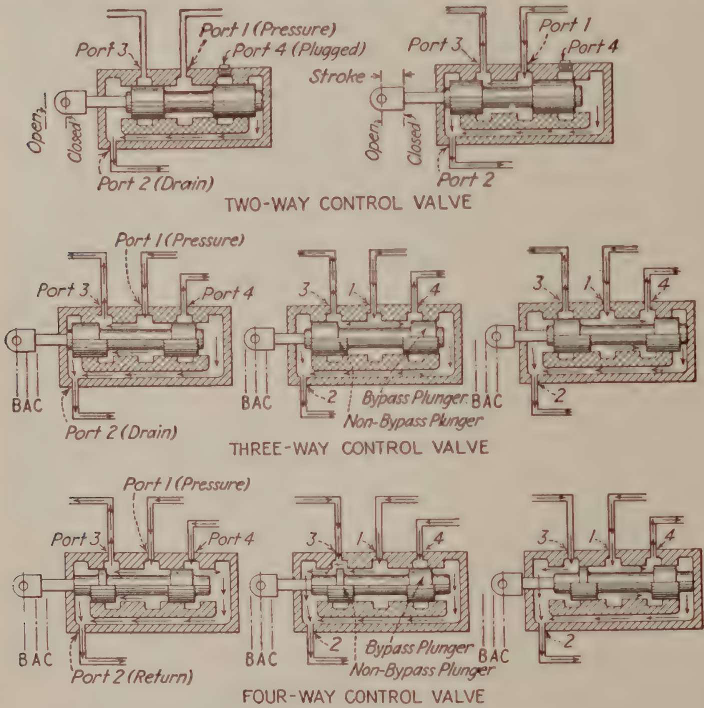


FIG. 324.—Diagrams of control valves.

The two-way is merely a rapid-acting opening and closing valve.

The three-way has no return port. It directs the oil from the pressure port to either port (3) or (4). Such a valve may be used, for example, to deliver oil alternately to two independent four-way valves. Port (2) is merely a drain.

The four-way is a directional control valve with the return port (2).

In the diagrams of the three-way and four-way valves, the upper half of the plunger represents the by-pass type. With a by pass valve the oil may be returned to the reservoir without going to either cylinder, thus without doing any work and therefore with little power consumption. (*Courtesy of The Oilgear Company.*)

force its way, against the spring-valve resistance, into the pressing cylinder. The oil, being exhausted from the other end of the pressing cylinder, flows freely through the valve on

that end by merely raising the ball. The clamping cylinder operates first, both forward and return.

Foot valves are used extensively in vertical hydraulic presses to give resistance to the *exhaust* flow. (See paragraph 357 and Fig. 327.)

355. Driven Units.—A rotary hydraulic motor is merely a reversed hydraulic pump. Such motors have been made and applied to lathes and other rotating-spindle machines, but the field for hydraulics in machine tools seems to be, at present, almost wholly for controlling a reciprocating movement, as in sliding tables and kindred constructions, and for feed-unit slides.

The reciprocating hydraulic-driven unit (piston and cylinder) has two general types, one in which the piston moves back and forth in the cylinder and the solid piston rods are fastened to the table (Fig. 325), and the other having the *cylinder* fastened to the table and *hollow* piston rods to conduct the oil to the stationary piston where it is turned back to push the cylinder (Fig. 326). In the latter design the rods are always in tension and a smaller rod may be used.

The term *differential*, as applied to hydraulic cylinders, is the ratio of difference of active area on each side of the piston. For example, in a machine with one piston-rod connection (a differential cylinder), the whole area of the piston toward the *blind end* (head) of the cylinder is acted upon, and the area of the *rod end* is less by the amount of the cross-sectional area of the piston rod. In a 2:1 differential cylinder the pushing area is twice the pulling area.

The cylinders illustrated in Figs. 325 and 326 are non-differential, to give equal pressures for reciprocating table movements of a surface-grinding machine, for example. The cylinders for shapers, planers, and presses are differential; the push needed may be two or three times that needed for the pull (see Fig. 327, also Fig. 328).

356. Cross-feed Mechanism.—Referring to Fig. 319, page 423, it will be observed that at each reversal of the table the

reverse lever (16) operates a cam (17) which works against a roller (18) in the end of the cross-feed valve plunger (19). This action pushes the valve plunger against a small spring (20) which instantly forces it back again; during this time, however, the valve has been opened and oil has been admitted

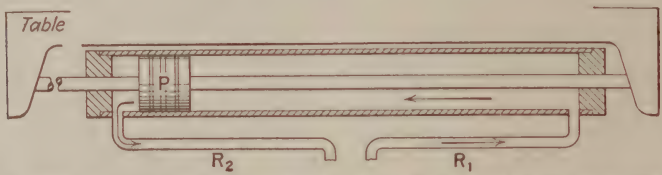


FIG. 325.—In this type of cylinder the piston rod is fastened to the table, and with the piston P is moved back and forth. As shown, the oil enters through R_1 and pushes the piston (and table) to the left, while oil on the other side exhausts through R_2. When the reverse valve operates, the oil from the pump enters through R_2 and the oil on the other side of the cylinder exhausts through R_1.

to the valve chamber (21) in front of the cross-feed impulse piston (22). This pressure of oil serves to push the piston (22) and the rack (23) until stopped by the feed-adjusting screw (24). The movement of the rack is communicated to the quadrant-pawl carrier (25) and to the pawl and ratchet

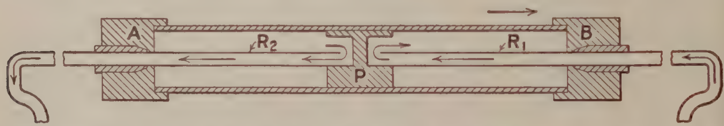


FIG. 326.—In this type the cylinder itself is fastened to the table, and the oil flows through *hollow* piston rods. In the diagram, A and B represent the cylinder heads. To move the cylinder (and table) to the right, as shown, the oil is pumped through the hollow rod R_1 in the direction of the arrow and exerts pressure against B. Since the piston P and the hollow piston rods are stationary, and the table is moving toward the right, the oil in the left end of the cylinder is being forced through the hollow piston rod R_2 to the reservoir. When the reverse valve operates, the flow of oil is reversed and the table moves in the opposite direction.

(26) thence to the cross-feed screw. The amount of the movement (feed) is determined by the position of the feed-adjusting screw (24).

It may be observed further that the return spring (27) of the impulse piston (22) forces the oil from the valve chamber

(21) across the space or "spool" on the piston (19) and out through the exhaust (28).

357. A 35-ton Hydraulic Press.—Figure 327 shows the installation of a hydraulic cylinder, pump, four-way control valve, resistance valve, pipe connections, pressure gauge, etc.;

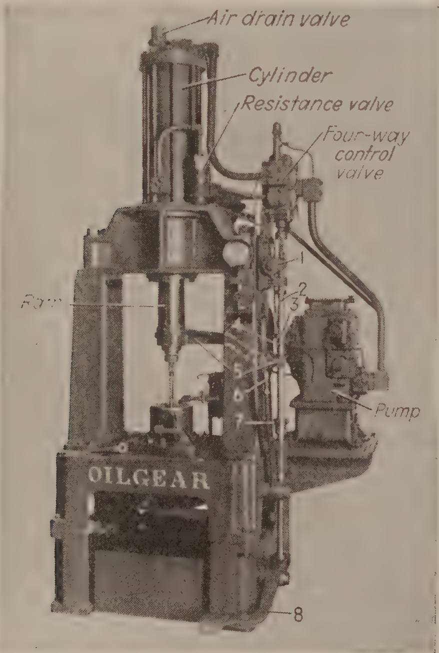


Fig. 327.—Thirty-five ton hydraulic press.

This figure serves to show the pump, the essential valves, and connections. In the commercial assembly of this press these units are built in, that is, they are enclosed within the frame for appearance as well as for protection. (*Courtesy of The Oilgear Company.*)

also the control rod and the stroke-adjusting collars that serve to move the control-valve plunger.

The control valve is bracketed to the side frame of the press and is operated by means of the control-rod mechanism. To start the ram moving downward, the hand lever (6) is pulled toward the operator (or the foot pedal (8) depressed) which raises the control rod (2) and the plunger in the control valve, thereby directing the flow of oil to the top of the cylinder.

The detent (1) holds the control rod and valve plunger in this position until the end of the ram arm (5) strikes the lower stroke-adjusting collar (7), thereby moving the control rod and valve plunger downward, which serves to direct the pressure flow of oil to the bottom end of the cylinder and to reverse the ram movement. As the ram moves upward, the end of the ram arm (5) compresses the spring (4) below the upper stroke-adjusting collar (3) slightly, and moves the plunger of the control valve up to the neutral or by-pass position. With the valve plunger in this position the full volume of oil from the pump is by-passed through the control valve and returned to the pump reservoir and the ram stops.

The resistance valve (see also paragraph 354 and Fig. 323) is used to restrict the oil in the bottom end of the cylinder sufficiently to prevent the piston, ram, and ram arm from dropping when the control valve is in the neutral by-pass position.

358. Rapid-traverse and Feed Circuit.—A common operating requirement of a hydraulic control system on machine tools, such as drills, boring machines, and milling machines, is of the rapid-traverse and feed classification. The work on a milling-machine table, for example, must be advanced nearly to the cutter at a relatively rapid rate in order to save time, then automatically slowed down to the proper feed rate before cutting begins to take place. The feed rate should be readily variable to accommodate various tool-cutting conditions. At the finish of the feed portion of the cycle it is necessary to reverse the movement of the worktable, and this may be done by hand, as shown in the table feed circuit illustrated in Fig. 328, or it may be accomplished by automatic means as is usually done in high-production shops. A spring "load-and-fire" latch mechanism[1] is often used for quick

[1] In a latch-and-fire or load-and-fire mechanism, the valve is latched against spring pressure by the operator when the cycle is started, and motion in one direction continues until a trip dog on the moving member unlatches, or "fires" the spring-loaded valve plunger. Automatic reversal of the moving member is thus accomplished.

reversal. Another and more common method of obtaining automatic reverse is the use of a pilot valve to operate the four-way valve. Both of these methods are employed with the aid of a cam or dog on the machine table. The cam is adjustable and causes the reversal to take place at any given point of the carriage advance during each cycle. The return to the starting position after reversal is at a high rate to keep the cycle time as short as possible. An automatic stop is usually provided.

The basic schematic diagram in Fig. 328 shows the pump *D* supplying oil under pressure to the reversing valve *C*. The action of this reversing four-way valve has been described. In the piping connection leading between the four-way valve and the *rod end* of the cylinder are shown three other valve units having certain functions to perform. One unit is a plunger-operated shut-off valve *E* which is closed when the plunger is depressed by the cam on the table and opened by an internal spring when the cam is withdrawn. A check valve *F* is also indicated, its function being to allow free flow in one direction at all times regardless of the position of the shut-off valve. The flow-control valve *G* consists of a variable orifice that may be easily adjusted, and it should be of the type which will meter the desired amount of oil regardless of a fluctuation in the pressure imposed upon it.

During the interval between cycles the operating lever is in its central or "stop" position. The four-way valve plunger is then causing the entire discharge from the pump to be directed back to the reservoir through the piping connection shown leading directly from the valve to the reservoir.

Having set the work in the machine, the operator causes the table to "rapid advance" by moving the lever to the "advance" position. Oil from the pump is then directed to the head or blind end of the cylinder, and the oil surrounding the piston rod in the rod end of the cylinder is discharged freely through the open shut-off valve *E* and the four-way valve *C* to the reservoir. The table will thus advance at a rate determined by the maximum pump volume until the plunger of the shut-off

valve E is depressed by the cam. After this valve is closed, the oil being exhausted from the rod end of the cylinder must escape through the flow-control valve G while the piston advances between opposing pressures. The rate of escape (the "metering out") is determined by the size of the orifice

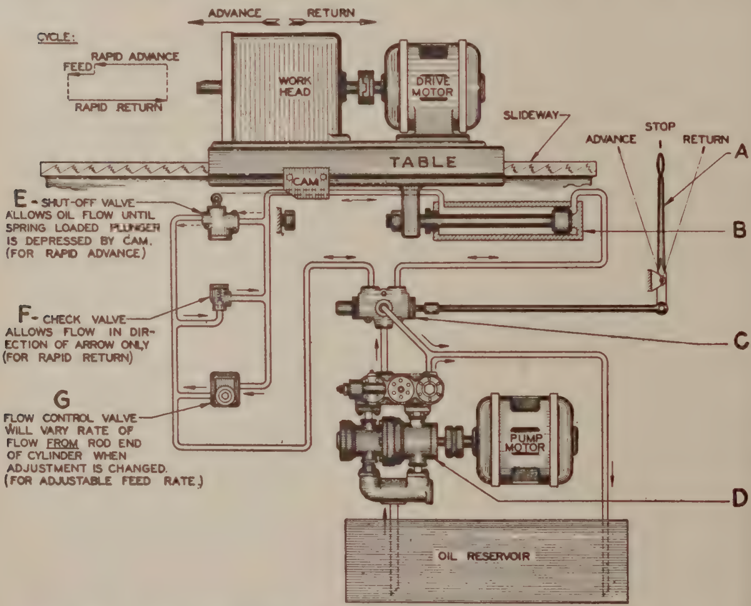


FIG. 328.—Schematic diagram of basic rapid-traverse and feed circuit.
A. Manual control lever. Automatic control may be obtained by use of pilot-operated or latch-type four-way valves.
B. Cylinder.
C. Directional control four-way valve, reverses flow of oil to cylinder, or, when at mid-position, directs pump flow of oil to reservoir.
D. Double pump and automatic control of pressure and volume. (*Courtesy of Vickers Incorporated.*)

opening in G, and the rate of movement of the table during the feed is thereby controlled. Owing to the opposing pressure condition imposed on the piston by the metering-out action, a smoother feed is obtained.

The reverse of the table movement is caused by throwing the control lever to the "return" position. The oil flow through the four-way valve C is immediately reversed and oil

under pressure is fed to the rod end of the cylinder after being circulated through the check valve *F*. During reversal both the shut-off valve *E* and flow-control valve *G* are ineffective, and a rapid return rate is thus maintained over the entire return distance. Oil from the head end of the cylinder meanwhile escapes freely to the reservoir. When moved to the "stop" position, the four-way valve again removes pressure from both cylinder connections, and allows the pump to circulate oil freely without power loss.

Referring to *D*, it will be noted that the assembly is made up of three units: the intake manifold; the double pump—the smaller-volume high-pressure pump at the left, and the larger-volume low-pressure at the right; and three adjustable valves—relief valve at the left, check valve in center, and unloading valve at the right. (The unloading valve is sometimes called an automatic by-pass valve.)

Assume, for example in a machine-tool circuit, that the relief-valve adjustment is set for 750 lb. per sq. in. and the unloading valve for 300 lb. per sq. in.

When the rapid traverse is taking place, in either direction, there is comparatively little resistance to the table movement since there is no feeding pressure. At this time the resistance to the piston movement is below the unloading valve adjustment (300 lb. per sq. in. in assumed case) and the circuit is open for the combined flow of oil from both the large- and the small-volume pumps. Thus: *large* volume at *low* pressure for rapid traverse.

When, however, a machine-tool cycle begins its feeding action (or when a press builds up pressure at the end of its closing stroke), the pressure in the system will build up to the relief-valve setting, which must be appreciably above the unloading-valve setting (750 lb. per sq. in. in assumed case). In the case of the machine-tool circuit, this pressure build-up is due to imposing a restriction in the metering-out end of the feed cylinder (valve *G* in Fig. 328). Inasmuch as the pressure builds up to the relief-valve setting, and this is above the setting of the unloading valve, the latter will be held wide

open against the spring pressure and will allow the entire volume from the larger volume pump to be unloaded or returned to the reservoir. That is, the larger pump during this period merely circulates oil, and no appreciable amount of

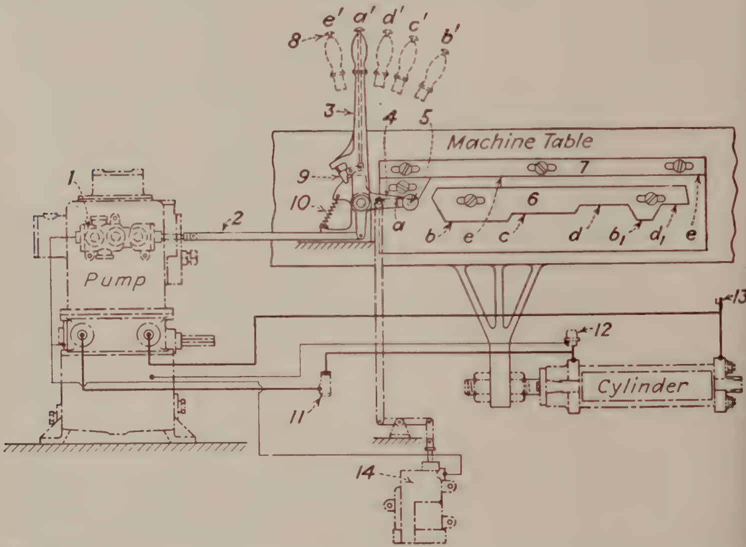


FIG. 329.—Diagram of cam control mechanism and oil circuit. *Oilgear* pump, valve, cylinder, etc. (*After diagram from The Oilgear Company.*)

(1) Six-way control valve, may be mounted on side of pump case, on frame or any non-moving part of machine; (2) valve stem connection to hand-control lever (3) and cam-roller arm (4); (5) cam-roller spindle, has ball bearings, and when in action follows the cam outlines *a*, *b*, *c*, etc. on camplates (6) and (7); (8) pushbutton for lifting latch (9) out of the notch in cam-roller (4) and thus releasing (3) and (2) from (4). This permits of operating the valve independently of the cam to stop or reverse the worktable at any point in case of emergency. (10) Tension spring between stationary bracket and cam-roller arm (4); (11) foot valve; (12) automatic air-drain valve; (13) air-drain petcock; (14) dashpot may be installed if a dwell at each end of feed is desired.

The letters *a*, *b*, *c*, etc., indicate the cam surfaces, and *a′*, *b′*, *c′*, etc., the corresponding positions of the control lever (3): *a*, neutral; *b*, rapid-traverse forward; *c*, fast feed; *d*, slow feed; b_1, same as *b*; d_1, same as *d*; *e*, rapid-traverse reverse to starting point and stop.

power is required to drive it. At this time only the volume of the high-pressure pump is used—*smaller* volume at *high* pressure for feeding. The check valve prevents loss from the high-pressure pump delivery.

Since the small-volume pump is selected as to size so it will be slightly more than adequate to take care of the maximum

feed rate of the given machine, a very small amount of oil will be discharged over the relief valve during the feed portion of the cycle, and returned, with that from the large pump, to the reservoir. Meanwhile the relief valve maintains the feed pressure at the given setting.

359. Automatic Control.—The various manufacturers provide commercial units of pumps, valves, and control devices for performing operation cycles when actuated manually or

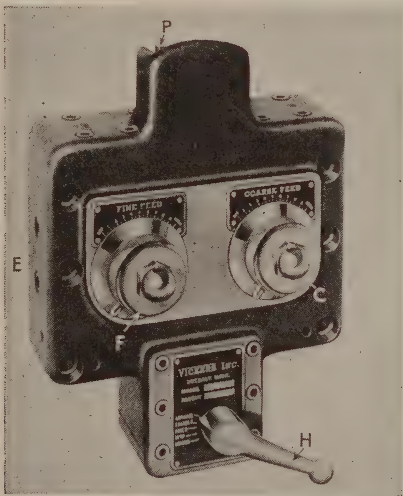


FIG. 330.—Control panel. *F*. Adjustment for fine-feed series. *C*. Adjustment for coarse-feed series. *H*, Hand control. *P*. Plunger for cam control. (*Courtesy of Vickers Incorporated.*)

automatically. In fact, several valves may be incorporated in one unit and controlled automatically, and in some systems the volume of the variable-displacement pump is automatically changed to suit the requirements.

In semiautomatic or full-automatic operation of the modern hydraulic machine tool, employing the rapid-traverse and feed circuit, a control mechanism operated by adjustable camplates is used. By this means the plunger or plungers of the control valve are moved to select the high-pressure and low-pressure volumes in the right direction at exactly the right time in the prescribed cycle of operations for which the

machine is set. Such a mechanism is indicated in the diagram Fig. 329. The control-valve unit (1) in this case is integral with the pump.

Many commercial applications use what is known as the *hydraulic control-panel unit.* Such a panel may combine the four-way valve, check valve, shut-off valve, flow-control valve, and auxiliary automatic-reversing and stop valves into one integral assembly. This eliminates nearly all piping and simplifies the installation. The panel illustrated in Fig. 330 is of this type and includes two flow-control valves, one for fine feeds and the other for the coarser feeds. As may be noted in the illustration, the control may be operated manually by the handle *H*, or automatically by cams on the machine table depressing the plunger *P*, or electrically by means of solenoids mounted behind the panel.

The subject of hydraulic power applications in machine tools is being advanced rapidly. It is very important to the progressive machinist. It does not involve difficult mechanical principles, but the applications are new and different, interesting and well worth the machinist's attention.

GEARS

CHAPTER XVIII

SPUR GEARS AND BEVEL GEARS

360. Introduction.—The purpose of this chapter is to give the beginner sufficient information to enable him to understand gear terms, the rules used in making spur gears and simple bevel gears, and the application of the rules necessary to turn up a gear blank in a lathe and form the teeth in a milling machine—and know what he is doing.

Certain gearing terms are defined, fundamental considerations of gear-tooth shape are introduced, and the rules a machinist should know how to apply are included for study and reference. In this connection it is advised that several treatises on gears, including complete tables of sizes for all gear parts, are published.

SPUR GEARS

361. Reason for Gears.—If two rolls as in *a* (Fig. 331) are in close contact and one is turned, the other will revolve. The circumference of the driven roll will move as many inches as the circumference of the driving roll moves *if there is no slip*, but the drive of B is dependent upon *friction* with A and only a very light load can be transmitted from A to B.

If, however, the faces of the two rolls are toothed as shown in *b* (Fig. 331), motion may be transmitted positively from A' to B' and as great a load may be transmitted as the strength of the teeth will permit. Rolls or wheels with teeth are called gears. When the rolls are cylindrical in shape with teeth parallel to the axis, the gears are called *spur gears*, and when the rolls are cone-shaped (bevel face), the gears are called *bevel gears*. If positive dependence could be placed upon frictional contact, gears would be unnecessary, but as there must invariably be a certain amount of slip when using any kind of drive

depending upon the friction of rolls, belts, etc., gearing is used to give a positive definite velocity ratio from one shaft or spindle to another.

To convert rotary gear motion into reciprocating motion, or *vice versa*, a rack is used. A *rack* is a straight rectangular strip with teeth formed in the face to mesh with gear teeth of corresponding size (pitch).

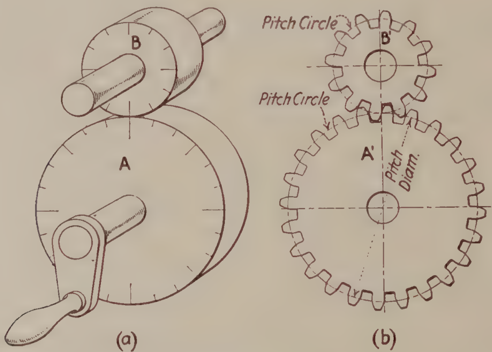


FIG. 331.—In (*a*) *B* is half as large as *A* and, with no slip, will make twice as many turns as *A*. In (*b*) the *pitch circle of B′* is half as large as the *pitch circle* of *A′*; therefore the gear *B′* will go twice as fast as *A′*.

362. The pitch circle or "pitch line" of a gear is the line that represents, in drawings and calculations, an imaginary surface corresponding to the original friction surface. The pitch circles of the two gears *A′* and *B′* are shown in *b*, Fig. 331, and it will be noted that they correspond to the friction surfaces of the two rolls *A* and *B*, respectively, their diameters being equal. The diameter of the pitch circle of a gear is called the *pitch diameter*.

The circles of the two rolls represent real surfaces; in the gears the pitch lines represent theoretical or imaginary surfaces. However, the pitch circle or, more correctly, the diameter of the pitch circle, *the pitch diameter*, is a very important factor in gearing; the relative velocities of the gears in mesh depend upon their *pitch diameters*, not upon their outside diameters, and further, having given the number of teeth, their shape and size depend upon the pitch diameter.

363. Tooth Parts.—It will be observed in Fig. 331 that when sizing the outside diameter of gear blanks, they must be made large enough to provide for the part of the tooth above the pitch circle; furthermore, the tooth *spaces* must be cut deep enough below the pitch circle to allow the teeth of the mating gears to engage properly. This radial distance between the pitch circle and the top of the tooth is called the *addendum* (Fig. 332), and between the pitch circle and the bottom of the tooth, the *dedendum*. In order that the top of the tooth of the gear shall not rub on the bottom of the space of the

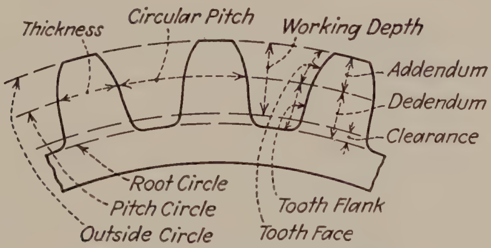


FIG. 332.—Parts of a gear tooth.

mating gear, the spaces are cut deep enough, to allow for *clearance*. That is, the dedendum is made equal to the addendum plus the clearance.

The *whole depth* of a gear tooth is the radial distance between the outside circle and the root circle and is equal to twice the addendum plus the clearance. The *working depth* is equal to twice the addendum.

The *thickness* of the tooth (circular thickness) is measured on the pitch circle (see 6, 7, and 9, page 446).

The *face* of a tooth is the surface between the pitch-line element and the top of the tooth, and the *flank* is the surface between the pitch-line element and the bottom, including the fillet.

In order that the relative speeds shall be correct, the addenda of mating gears must be the same; and in order that the gear teeth shall transmit motion smoothly they must be properly shaped. How the addendum, working depth, clear-

ance, etc., are calculated will presently be explained; other definitions and explanations are in order first.

364. Circular Pitch.—The distance between the center of one tooth and the center of the next measured on the pitch line is called the *circular pitch.* (In racks it is called the *linear pitch.*) There are as many circular pitches in a gear as there are teeth in that gear.

The term "pitch" is used in machine work, to denote a size. Before the days of indexing devices, formed cutters, and gear-cutting machines, most gears were cast gears, the patterns were laid out in the pattern shop, and then the gears were cast and filed more or less to shape. Circular pitch was then used to designate the size of the gear tooth, and easily measured pitches such as ¼ in., ½ in., ¾ in., etc., were used. The pattern-maker used the circular pitch (or more correctly, he used the chord of the circular pitch or "chordal pitch") to space the teeth in the pattern gears, and the calculations for diameter, center distance, etc., were based on circular pitch. Today, however, the circular pitch is used only in calculations for gears of 3-in. circular pitch and larger, for the reason that a simpler and better system for the smaller pitches has been devised.

365. Diametral-pitch Idea.—The circumference of a circle is 3.1416 times the diameter, consequently if either is a simple figure or fraction, the other is a decimal, more or less awkward to handle in calculations. There is no question of the value of a gear system in which the *pitch diameters* rather than the pitch circumferences are simple dimensions. Indexing devices have been developed for accurately spacing the teeth and consequently no layout for circular pitch or even chordal pitch is necessary, and further, since the formed tooth cutter will form the teeth within commercial limits of accuracy, no layout for the tooth shape is necessary in the shop. Therefore, there being no particular advantage in having the circular pitch an even number or an easily used fraction, and every advantage in having a system which simplifies calculations and measurements, the *diametrical-pitch system* was devised.

This system bases the gear calculations and measurements on the pitch diameter rather than on the pitch circumference, and the pitch diameters, center distances between gears, working depth of teeth, etc., are easily handled figures and fractions.

366. The Diametral Pitch.—In the diametral-pitch system the pitch diameter is made a convenient dimension, 2 in., 3 in., 3½ in., etc. A designer may put any number of teeth desired on a gear of a given diameter, for example, on one gear of 2-in. pitch diameter he may put 20 teeth and on another gear, same pitch diameter, he may put 40 teeth. On the

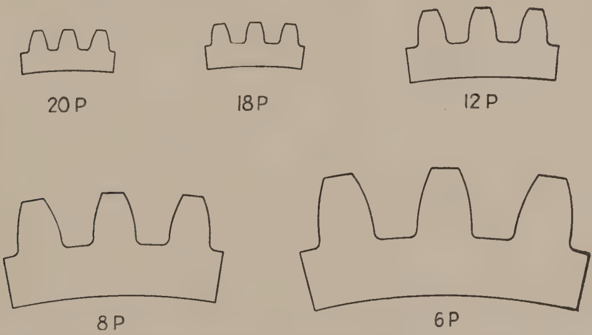


FIG. 333.—Shows relative sizes of gear teeth of five different pitches.

20-tooth gear he will have a larger stronger tooth, on the other the teeth will be half as large but the gear will run more quietly. These gears, of course, will not mesh with each other but either will mesh with a gear having teeth of corresponding size. Note that on one gear (2-in. pitch diameter, 20 teeth) there are 10 teeth to each inch of pitch diameter—on the other gear (2-in. pitch diameter, 40 teeth) there are 20 teeth to each inch of pitch diameter. In this system the one is a "10-pitch gear" and the other is a "20-pitch gear."

The diametral pitch of a gear is the *number* which expresses the number of teeth in that gear for each inch of its pitch diameter. It expresses also the *size* of the gear tooth, as will be explained presently. Diametral pitch is always represented by the letters *DP;* circular pitch *CP.* In gearing,

whenever the word "pitch" is used alone, *diametral* pitch is meant. Perhaps a better idea of diametral pitch may be obtained more quickly if the student understands the module.

367. The Module (in English Measure).—The module (meaning measure) is the same proportional part of the pitch diameter as the circular pitch is of the pitch circumference. That is, if the pitch diameter of a gear is divided into as many equal parts as there are circular pitches (teeth) in the gear, each part will be a definite distance which is called the module. (See Fig. 334.) In a gear, for example, 3-in. pitch diameter, 30 teeth, the module is $\frac{1}{10}$ in., and in a gear 2-in. pitch diameter, 24 teeth, the module is $\frac{1}{12}$ in. Note in each case, that the module is a fractional part of an inch and equals one divided by the pitch $\frac{1}{DP}$. In other words, module is the reciprocal of the diametral pitch. The term module is seldom used in this country, the expression $\frac{1}{DP}$ is used instead.[1]

NOTE.—As a possible means of making clearer the meaning and value of diametral pitch and module this note is added:

The circular pitch is 3.1416 times as large as the module, or the module is $\frac{1}{3.1416}$ as large as the circular pitch. Therefore it is impossible to have both the circular pitch and the module an even number. It is better to have the pitch diameter of gears some common dimension such as 3 in., 3½ in., 4 in., 6 in., 8 in., etc., and to let the circular pitch be what it may; consequently it is common practice when designing cut gears, to make the module some nominal part of an inch such as $\frac{1}{12}$ in., ⅛ in., ¼ in., etc. Now these common fractions (modules) could be used in gear calculations, but as it is easier to use whole numbers than it is to use fractions, the reciprocal of the fraction is used and it is called the *diametral pitch*. For instance, it is easier to say "12-pitch gear" than it is to say "$\frac{1}{12}$-inch module gear" and more convenient to express and perform multiplication by 12 than division by $\frac{1}{12}$.

368. Gearing Nomenclature.—The understanding of gears, even spur gears and the simplest kinds of bevel gears as discussed in this chapter, means, of course, a knowledge of the terms used. Some of these gear terms have already been ex-

[1] In metric gears module is used and the term diametral pitch is not used (see page 456).

plained. For some time past, committees have been engaged in developing standards for the terms, abbreviations, and symbols for various gear elements. Many of the old terms have been approved, and some changes have been made and approved. The terms and definitions used in this book (paragraphs 369 and 388) are from "Recommended Practice of the American Gear Manufacturers' Association for Gearing Nomenclature."

It takes years to establish a "standard," and during this time manufacturers make and sell hundreds and thousands of their own designs of, say, tapers, machine keys, and gears. For several reasons, some of them no doubt sound reasons, these companies adhere to their sizes, etc., even after a standard has been well established. This is a fault if the accepted standard is as good or better than their design, but it is nevertheless a condition the machinist has to meet. He can usually meet it if he has an understanding of the principles involved, plus resourcefulness.

The machinist should know the meaning of the commonly used gear terms; he should be able to make the necessary calculations for spur gears, and the simpler types of bevel gears. It is not necessary to learn all the rules, but it is well worth while to know where to find them when needed, and how to *use* them.

369. Definitions and Rules, Spur-gear Elements and Tooth Parts (Fig. 334).—These definitions are in alphabetical order.

1. *Addendum* is the radial or perpendicular distance between the pitch circle and the top of the tooth; equals 1 divided by the diametral pitch. (This may be multiplied by a factor for special addenda.)

2. *Base diameter* is the diameter of the circle from which the involute is generated; equals pitch diameter times the cosine of the pressure angle.

3. *Bore diameter* is the diameter of the hole in the gear.

4. *Bottom land* is the surface between the flanks of adjacent teeth.

5. *Center distance* is the shortest distance between the axes of mating gears.

6. *Chordal addendum* is the radial distance from the circular thickness chord to the top of the tooth. To obtain: Subtract from 1 the cosine of the angle obtained by dividing 90 deg. by the number of teeth; multiply

the result by the pitch diameter and then divide by 2; add this amount to the addendum. (The chordal addendum and chordal thickness are used when a high degree of accuracy is required in measuring gear teeth.)

7. *Chordal thickness* is the length of the chord subtended by the circular thickness. To obtain: Multiply the pitch diameter by the sine of the angle obtained by dividing 90 deg. by the number of teeth.

8. *Circular pitch* is the distance on the circumference of the pitch circle between corresponding points of adjacent teeth; equals 3.1416 divided by the diametral pitch.

9. *Circular thickness* is the thickness of the tooth on the pitch circle; equals 1.57 divided by the diametral pitch. See also (6) and (7).

10. *Clearance* is the radial distance between the top of a tooth and the bottom of the mating tooth space; equals (usually) 0.157 divided by the diametral pitch.

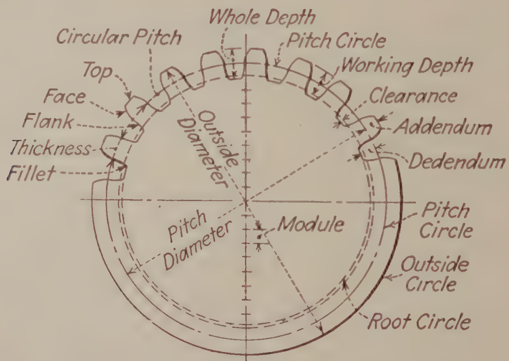


FIG. 334.—Spur-gear elements and tooth parts.

11. *Dedendum* is the radial or perpendicular distance between the pitch circle and the bottom of the tooth space; equals (usually) 1.157 divided by the diametral pitch.

12. *Diametral pitch* is the ratio of the number of teeth to the number of inches in the pitch diameter. It indicates the number of teeth in the gear for each inch of pitch diameter; equals number of teeth divided by the pitch diameter. (See also paragraph 366.)

13. *Face width* (face of gear) is the width of the pitch surface.

14. *Face of tooth* is the surface between the pitch-line element and the top of the tooth.

15. *Flank* of tooth is the surface between the pitch-line element and the bottom. It includes the *fillet*, which is the curved surface which adjoins the bottom land of the tooth space.

16. *Gear ratio* is the ratio of the numbers of teeth in mating members.

17. *Interference* is contact between meeting teeth at some point other

than along the line of action. In the gears with a small number of teeth special provision is made to avoid interference even to the extreme of an undercut. (See 34 and Fig. 335.)

18. *Involute:* See paragraph 371 and Fig. 336.

19. *Line (path) of action* is that portion of the common tangent to the base circles along which contact between mating involutes occurs. (See Fig. 338.)

20. *Module:* See paragraph 367.

21. *Outside diameter* is the diameter of the circle that contains the tops of the teeth.

22. *Pitch circle* is the circle through the pitch point having its center at the axis of the gear.

23. *Pitch circumference* is circumference of the pitch circle.

24. *Pitch cylinder* is the cylinder corresponding to the pitch circle.

25. *Pitch diameter* is the diameter of the pitch circle; equals number of teeth divided by the diametral pitch.

26. *Pitch line* is the line formed by the intersection of the pitch surface and the tooth surface.

27. *Pitch point* is the intersection, between the axes, of the line of centers and the common tangent to the base circles.

28. *Pitch surface* is the surface of the pitch cylinder.

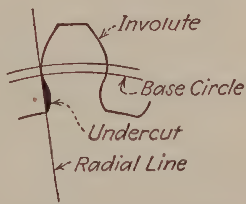


FIG. 335.—Shows a gear-tooth undercut.

29. *Pressure angle* of involute gears is the angle between the line of action and a perpendicular to the common center line of mating gears; in any type of gear it is equal to a tangent to the tooth profile and a line perpendicular to the pitch surface; 14½ deg. and 20 deg. are standard pressure angles. (See Fig. 338.)

30. *Root circle* is the circle containing the bottoms of the tooth spaces.

31. *Root diameter* is the diameter of the root circle; equals pitch diameter minus two dedenda.

32. *Thickness*, see 7 and 9.

33. *Tooth face, fillet,* and *flank* (see 14 and 15).

34. *Tooth surface* includes both face and flank.

35. *Undercut* is that portion of the tooth surface, adjacent to the involute, lying inside a radial line passing through an imaginary intersection of the involute and the base circle (Fig. 335). Such a tooth outline is found in gears with few teeth.

36. *Whole depth* is the radial distance between the outside circle and the root circle; equals addendum plus dedendum.

37. *Working depth* is the greatest depth to which a tooth of one gear extends into the tooth space of a mating gear; equals addendum of pinion plus addendum of gear, or (usually) twice the addendum of either.

370. Rules and formulas for dimensions of spur gears for 14½-deg. composite system; 14½-deg. involute (generated) system, and 20-deg. full-depth stub involute system. (For information concerning stub-tooth gears see page 454.)

To find	Having	Rule	Formula
1. Diametral pitch	Circular pitch	Divide 3.1416 by the circular pitch	$DP = \frac{3.1416}{CP}$
2. Diametral pitch	Number of teeth and pitch diameter	Divide number of teeth by pitch diameter	$DP = \frac{N}{PD}$
3. Diametral pitch	Number of teeth and outside diameter	Add 2 to the number of teeth and divide by the outside diameter	$DP = \frac{N + 2}{OD}$
4. Circular pitch	Diametral pitch	Divide 3.1416 by the diametral pitch	$CP = \frac{3.1416}{DP}$
5. Circular pitch	Pitch diameter and number of teeth	Divide the pitch diameter of the product of 0.3183 and the number of teeth	$CP = \frac{PD}{0.3183N}$
6. Number of teeth	Pitch diameter and diametral pitch	Multiply the pitch diameter by the diametral pitch	$N = PD \times DP$
7. Number of teeth	Outside diameter and diametral pitch	Multiply the outside diameter by the diametral pitch and subtract 2	$N = OD \times P - 2$
8. Pitch diameter	Number of teeth and diametral pitch	Divide the number of teeth by the diametral pitch	$PD = \frac{N}{DP}$
9. Pitch diameter	Outside diameter and addendum	Subtract two times the addendum from the outside diameter	$PD = OD - 2s$
10. Outside diameter	Number of teeth and diametral pitch	Add 2 to the number of teeth and divide by the diametral pitch	$OD = \frac{N + 2}{DP}$
11. Outside diameter	Number of teeth and pitch diameter	Add 2 to the number of teeth and divide this sum by the quotient of number of teeth divided by the pitch diameter	$OD = \frac{N + 2}{\frac{N}{PD}}$
12. Outside diameter	Pitch diameter and diametral pitch	Add to the pitch diameter the quotient of 2 divided by the diametral pitch	$OD = PD + \frac{2}{DP}$
13. Thickness of tooth	Diametral pitch	Divide 1.57 by the diametral pitch	$CTh = \frac{1.57}{DP}$
14. Clearance	Diametral pitch	Divide 0.157 by the diametral pitch	$C = \frac{0.157}{DP}$
15. Whole depth of tooth or tooth space	Diametral pitch	Divide 2.157 by the diametral pitch	$WD = \frac{2.157}{DP}$
16. Center distance	Pitch diameters	Divide sum of the pitch diameter of the pair of gears by 2	$CDi = \frac{PD + pd}{2}$
17. Center distance	Numbers of teeth and diametral pitch	Add together the numbers of teeth and divide one-half the sum by the diametral pitch	$CDi = \frac{\frac{1}{2}(N + n)}{DP}$

371. Shape of Gear Tooth.—To obtain a smooth, quiet, uniform rolling action (conjugate gear-tooth action) of mating gears of the same pitch regardless of size, the teeth must be properly shaped. The experience of many years has gradually limited the shape of gear teeth to the involute curve, or a composite of involute and cycloidal curves. (See Fig. 336.)

These curves are not laid out by the machinist or even by the average toolmaker; they are, however, a very important feature of gear-tooth design and as such should be of interest to the machinist (see Fig. 337). It has been learned that

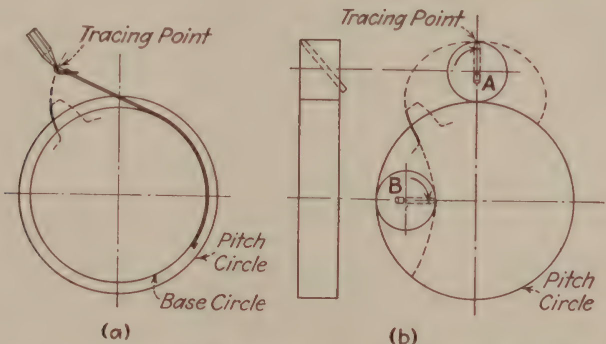


FIG. 336.—Generating (*a*) involute curve, (*b*) cycloidal curves—outside of circle, *epicycloid*, inside of circle, *hypocycloid*. These curves are interesting as showing the theory of gear-tooth shape. A high degree of accuracy is employed in making the cutters and attention must be given to have them sharpened properly.

gears formed according to these curves can be made economically, and, when running together, have a *rolling action*, one against the other, at a prescribed *pressure angle*, in interchangeable gears of whatever size. Also, there is an absence of interference—the tendency of the top of one tooth to dig into a mating tooth—except in gears with few teeth where it is easily corrected.

The gears cut with rotary cutters, as in the general-purpose machine shop, are of the *composite system*, which is *based upon the involute curve*, and have that curve in the proximity of the pitch line but are modified by having the cycloidal curves for

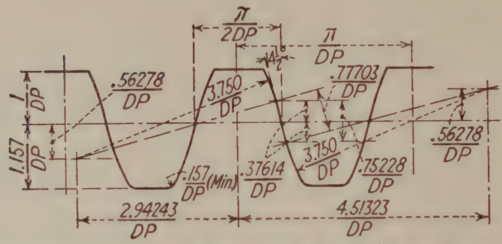


FIG. 337.—Approximation of basic rack for 14½-deg. composite system. It is, in fact, the basic rack for the "standard involute gear" with a base circle of 0.968 *PD*, slightly modified by the cycloidal curves at the upper and lower portions of the teeth. Without this modification the gears with few teeth would be seriously undercut.

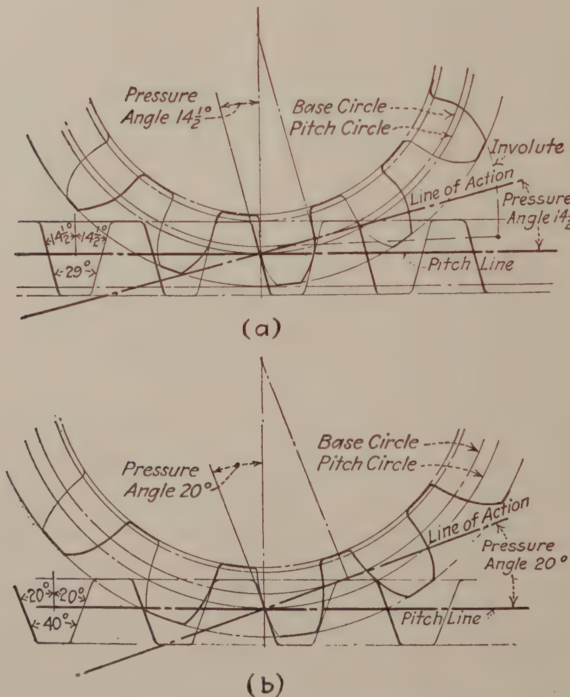


FIG. 338.—Gear and rack: (*a*) 14½-deg. pressure angle; (*b*) 20-deg. pressure angle. Note that the tooth in (*b*) is proportionately shorter: this is a "stub tooth."

the remainder of the surface of the tooth. (See Fig. 337.) The modification is for the purpose of eliminating the interference on gears with the smaller numbers of teeth. The cutters are accurately formed to give the composite involute-cycloid curves on the tooth profile.

372. The Base Circle and Pressure Angle.—The base circle[1] of the gear (corresponding to the cylinder from which the involute curve is generated) is somewhat smaller than the pitch circle to give a profile of the tooth which will have the desired pressure angle.

Referring to Fig. 338, it will be observed that the pressure of one gear tooth against another is at right angles to the profile of the tooth along the line (or path) of action. This line of action is not tangent to the pitch circle but is tangent to the base circle and therefore forms an angle with the pitch line. (In mating gears the pitch line as shown in the figure would be a common tangent to the pitch circles of both gears.)

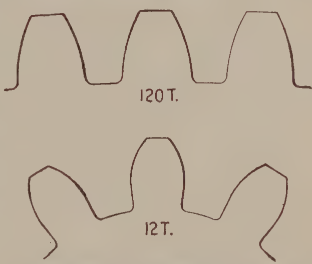


Fig. 339.—Shows portions of two gears of same pitch, 120 teeth and 12 teeth. Note the difference in the shapes of the teeth and also in the grooves between the teeth.

Angles of 14½ deg. and 20 deg. are standard pressure angles. Formerly the angle of 14½ deg. was the only standard, but the 20-deg. angle has found favor for the fast-running gears with fewer teeth since it reduces the need of undercutting and hence gives a longer line of tooth action and therefore a smoother and more quiet action.

[1] With 14½-deg. pressure angle the diameter of base circle is 0.968 of pitch diameter; with 20-deg. pressure angle the diameter of base circle is 0.940 of pitch diameter. (Diameter of base circle equals pitch diameter of gear multiplied by cosine of pressure angle.)

The terms "involute," "base circle," "pressure angle" relate more particularly to gear design than to the operation of cutting gears. Those interested in obtaining further information are referred to "Treatise on Gearing," Brown & Sharpe Mfg. Co., Providence, R. I., or to "Standard Gear Book," Trautschold, McGraw-Hill Book Company, Inc., New York.

In any gear the shape of the tooth is more or less curved; the smaller the gear of a given pitch, the more it curves. This is illustrated in Fig. 339. Theoretically, to obtain a smooth rolling action between the pairs of gear teeth in mesh would require a different tooth curve, a different shape of tooth space, for each size of gear of the same pitch, this difference being more pronounced in the smaller gears. However, it has been found by experience that a set of eight cutters for each pitch will serve to cut all sizes of gears from 12 teeth to a rack and give commercially satisfactory results. Figure 340, which represents a set of cutters for 10 pitch, illustrates how the shapes of the tooth spaces vary.

373. Gear Cutters.—Cutter manufacturers have adopted the following system (originated by Brown & Sharpe Mfg. Co.) of numbering the cutters for involute gear teeth:

Involute Gear Cutters (Brown and Sharpe System)

No. 1 will cut gears from 135 teeth to a rack
No. 2 will cut gears from 55 teeth to 134 teeth
No. 3 will cut gears from 35 teeth to 54 teeth
No. 4 will cut gears from 26 teeth to 34 teeth
No. 5 will cut gears from 21 teeth to 25 teeth
No. 6 will cut gears from 17 teeth to 20 teeth
No. 7 will cut gears from 14 teeth to 16 teeth
No. 8 will cut gears from 12 teeth to 13 teeth

(Cutters made accurate as for the smallest gear in its range)

If a cutter is wanted for a gear, 40 teeth, 8 pitch, then the cutter required will be No. 3, 8 pitch, inasmuch as a No. 3 cutter will cut all gears containing from 35 to 54 teeth, inclusive.

For those who require a finer division of the number of teeth to be cut with each cutter the manufacturers will furnish cutters in half numbers as follows:

Number of cutter	Range	Number of cutter	Range
1½	80 to 134 teeth	5½	19 to 20 teeth
2½	42 to 54 teeth	6½	15 to 16 teeth
3½	30 to 34 teeth	7½	13 teeth
4½	23 to 25 teeth		

374. Full-depth 14½-deg. and 20-deg. Involute Gears.—Most gears are made in quantities in gear-generating machines and are based on the involute alone because they can be more easily and accurately generated. They are made in 14½-deg. and 20-deg. full-depth systems. These gears are often made especially for the purpose intended and may be somewhat modified from the basic standards, the racks of which are illustrated in Fig. 341. Certain modifications are listed in

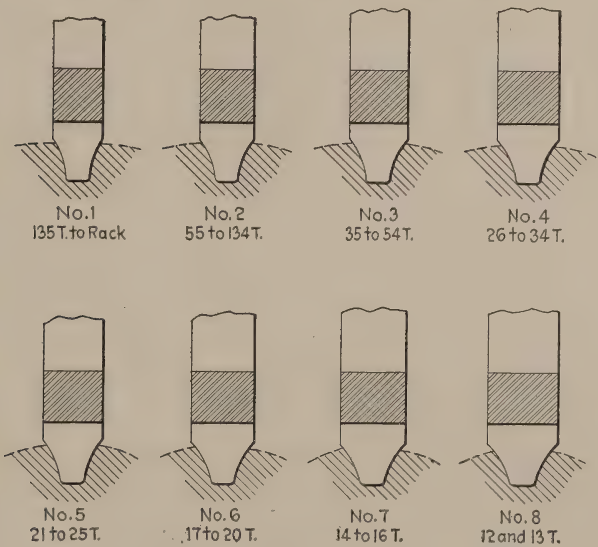


FIG. 340.—The set of eight cutters for 10 *DP*.

tables[1] and no doubt some of them will eventually become standard. These changes do not apply to composite-system gears cut by rotating cutters in a milling machine.

375. The 20-deg. Stub Tooth.—Where extra strength of the gear is needed, or when both mating gears have a smaller number of teeth and fast speed with smooth quiet action is essential as, for example, in automobile transmission gears, the stub

[1] For special information, tables of sizes, etc., consult "American Machinst's Handbook," or "Standard Gear Book," both published by the McGraw-Hill Book Company, Inc., New York.

tooth with 20-deg. pressure angle is used. The stub tooth adopted by the American Gear Manufacturer's Association is illustrated in Fig. 342, with the sizes of tooth parts. The rules and formulas for finding the gear dimensions are the same as those on page 448, except for the following substitutions:

$$(3)\ DP = \frac{N + 1.6}{OD};\quad (7)\ N = OD \times DP - 1.6;\quad (10)\ OD = \frac{N - 1.6}{DP}$$

$$(11)\ OD = \frac{N + 1.6}{\frac{N}{PD}};\quad (12)\ OD = DP + \frac{1.6}{DP};\quad (14)\ C = \frac{.2}{DP};\quad (15)\ WD = \frac{2.2}{DP}$$

The Fellows Gear Shaper Company's system is based on two standard-involute diametral pitches, as for example $\frac{4}{5}$. The numerator indicates the diametral pitch to be used in calculating the thickness and the diametral pitch; the denomina-

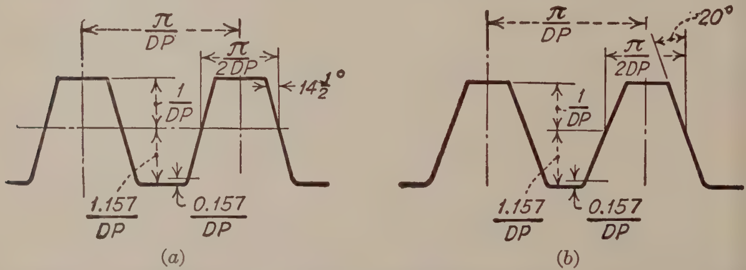


FIG. 341.—(a) Basic rack of 14½-deg. generated gear-tooth system; (b) basic rack of 20-deg., full-depth, gear-tooth system.

tor indicates the diametral pitch to be used in calculating the addendum and the working depth (equals two addenda); the clearance equals $\frac{1}{8}$ of the working depth. The calculations for $\frac{4}{5}$ stub gear, for example, are as follows: Thickness is $\frac{1.57}{4}$ same as for 4*DP*; addendum is $\frac{1}{5}$, equals 0.200, same as for 5*DP*; working depth equals two addenda, equals 0.400, same as for 5*DP*; clearance is $\frac{1}{8}$ of the working depth, equals 0.050; depth below pitch line equals addendum plus clearance, equals 0.250; whole depth equals addendum plus depth below pitch line, equals 0.450.

376. Values Not Standard.—The composite gear tooth with a 14½-deg. pressure angle (Fig. 337) made according to the

diametral-pitch system as described in the preceding pages is regarded in this country as standard. The metric gears, proportioned exactly the same, the difference in sizes being due to the difference in the units of measurement (English and metric) are regarded as standard in the countries using the metric system.

There is no doubt about the value of having standards and holding to standards as far as practicable; on the other hand, perhaps no standard is the best for all conditions. For example, special tapers, special screws, and special gears are often better adapted for a given purpose than standard sizes would be. Also new conditions, improved facilities, wider

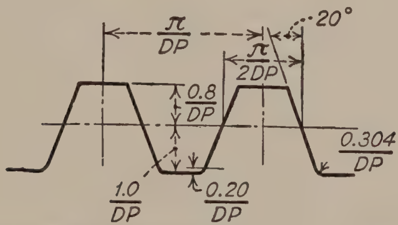


FIG. 342.—Basic rack of 20-deg. stub-tooth gear system.

experience, and more thorough investigation may result in new standards.

The automobile is responsible for a new series of thread pitches now generally accepted as the National Fine (*NF*). The automobile is responsible also for the increased use of the 20-deg. pressure-angle gear.

Special gears require special cutters. These cutters may be obtained from cutter manufacturers or possibly may be already available, but in order to duplicate a special gear or to make a gear which will mesh with a special gear requires on the part of the operator or foreman a general knowledge of gear standards and in addition, *certain information concerning that particular gear.* Whether it is 14½-deg. or 20-deg., full-depth or stub gear, with or without modifications such as increased addendum on the pinion and decreased outside diameter on

the mating gear, and sometimes whether or not it is a metric gear must be known.

377. Metric Gears (the module, metric measure).—In metric gears the sizes are expressed in millimeters, and the dimensions of gear teeth are expressed by reference to the *module.* Diametral pitch is not used because the millimeter being so small a dimension (0.03937 or about $\frac{1}{25}$ in.) modules in whole numbers may be used to designate sizes in common use. For example, a metric gear with a module of 2 mm. (*M* 2 metric gear) is about the same size as a 12*DP* gear (exactly 12.7*DP*). Cutters for metric gears, eight for each pitch as in diametral-pitch system, are regularly furnished by cutter manufacturers. For further information concerning metric gears see page 490. Attention is called to the fact that in the formulas given in this table, *M* is the reciprocal of *DP* in the formulas given on page 448 for the diametral-pitch system.

Questions on Spur Gears

1. Watch two engaging gears run. Can you imagine the "original friction surfaces" of the two "pitch cylinders?"

2. Being very careful of your fingers hold a piece of chalk in a position to draw a circle on each one of the revolving gears to represent the surfaces of the two pitch cylinders. What are these circles called?

3. What are the diameters of these circles called?

4. Stop the gears and then turn by hand until a tooth of one gear is exactly between two teeth on the other gear. Note the space between the top of the tooth of the one gear and the bottom of the groove of the other gear. What is this space called?

5. What part of the tooth is the addendum? Dedendum? Working depth? Is the working depth equal to the whole depth? What is it equal to?

6. What is the circular pitch of a gear?

7. What is meant by the module of a gear? In a given gear how much greater is the circular pitch than the module?

8. If a gear is 4-in. pitch diameter, 40 teeth, (1) how many modules in the pitch diameter? (2) How many modules to each inch of pitch diameter? (3) How many teeth in the gear to each inch of pitch diameter? (4) What is the *diametral pitch* of the gear?

9. As you think of a 16 *DP* gear do you visualize a tooth about $\frac{1}{8}$ in. deep? Do you visualize an 8 *DP* gear tooth as about $\frac{1}{4}$ in. deep? Explain. Why about $\frac{1}{8}$ in. or about $\frac{1}{4}$ in. and not exactly $\frac{1}{8}$ or $\frac{1}{4}$ in.?

10. What is the difference between a "one-quarter-inch module gear" and a "4-pitch gear?"

11. The whole depth of a gear tooth is 2.157 *DP*. Explain where you get the 2.157.

12. It is usually a simple matter to get from a broken gear or a worn gear sufficient information to calculate the sizes for a new gear. The first thing to get is the pitch. In the first calculation the answer may be a fraction but it will be so near a whole number that no doubt this whole number may be taken as the pitch. The outside diameter of an old gear that is to be replaced is $3\frac{21}{23}$-in. scale measurement, and there are 42 teeth on the gear. What is the pitch?

13. What is the exact diameter the new gear should be turned?

14. Suppose you should measure across the diameter of the old gear and find that from the *bottom* of one tooth to the *top* of the opposite tooth was a trifle less than $3\frac{1}{2}$ in. How would you find the pitch?

15. A machinist apprentice had to make two 10*DP* gears, 20 teeth and 40 teeth, respectively. He turned the blanks to the correct outside diameters. What sizes did he turn them?

16. Then he got a No. 3 cutter 10 *DP* from the toolroom and cut both gears with this cutter. What mistake did he make?

17. However, the gear was not spoiled. Why not?

18. Certain manufacturers of high-grade machine tools advertise "Our spindle-driving gears, etc., are cut with special cutters for the particular size and pitch of gear to insure smooth, quiet running." Just what does this mean?

19. Why is the "module" used in calculating metric gears and the diametral pitch in calculating for gears in English measure.

20. What is your understanding of the term "standard" as used in machine-shop practice?

21. What differences are usually to be found between the standard-tooth and the stub-tooth gear.

BEVEL GEARS

378. Introduction.—One should have a working knowledge of the parts and principles of the spur gear before attempting to study the bevel gear. Having this knowledge of spur gears, the subject of bevel gears should prove easy to understand if studied step by step in logical sequence. This text is presented in the following order:

1. Preliminary discussion and definitions.
2. Instruction for laying out gears. A layout is advisable to fix in mind certain necessary knowledge as well worth while for the machinist as for the draftsman.

3. Definitions and rules, bevel-gear elements, and tooth parts.

4. Example showing application of the rules. Size of gear selected is the same as for layout (2).

5. Cutting a bevel gear in a milling machine.

Do not rush. Try to understand each step before proceeding to the next.

379. Pitch Cylinders, Pitch Cones, Spur Gears, and Bevel Gears.—In the same way, as explained in spur gearing, that the motion of one cylinder will cause motion in a parallel

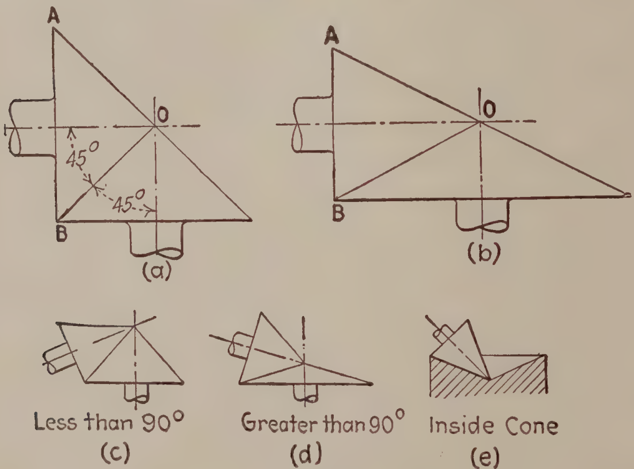


FIG. 343

cylinder that touches it, motion may be communicated from one shaft to another at an angle to it (whose center lines would meet if sufficiently prolonged) by means of cones in close contact. The apex of each cone is at a point where the center lines of the shafts would meet. Motion may be communicated in the desired velocity ratio (Fig. 343, *a* and *b*) and at the desired angle (*c*, *d*, and *e*).

In the study of spur gears it was learned that positive motion may be transmitted between parallel shafts by means of spur gears, and that spur gears are, in effect, "pitch cylinders" with teeth built on the cylindrical surfaces. Bevel

gears are, in effect, "pitch cones" with teeth built on the conical surfaces.

Spur gears communicate motion between parallel shafts. These shafts may be (within limits) any distance apart, and motion may be communicated (within limits) in any desired velocity ratio. Similarly, bevel gears communicate motion between shafts whose axes meet when prolonged.

In a pair of gears, spur or bevel, the smaller is often called the *pinion.*

Bevel gears are called *miter gears* when they are of the same size and transmit motion at right angles.

380. Pitch Cones.—The cones which represent in bevel gears the original friction surfaces are called the *pitch cones.* It is on frustums (portions at the large end) of these cones that the teeth of bevel gears are built, similarly as the teeth of spur gears are built on the pitch cylinders.

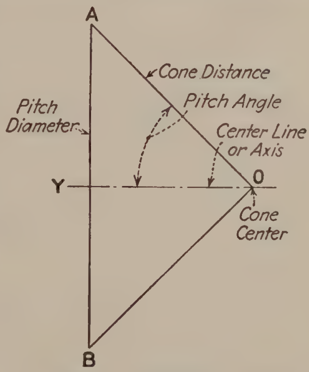


FIG. 344.—Elements of pitch cone. These elements apply to the bevel gear exactly as they apply to the pitch cone.

It is important that one should have a very clear understanding of the elements of the pitch cone, for the reason that although the bevel gear itself is only a portion of a cone, in drawings the whole cone is laid out and in calculations the whole cone is considered.

In the drawing (Fig. 344) the triangle AOB represents the pitch cone with the cone center at O. The line OY is the *center line* (axis) of the cone, and the lines OA and OB represent the *cone* (*apex*) *distances.* Either angle AOY or BOY is the *pitch angle.* The line AB will equal the *pitch diameter* of the bevel gear built on this cone.

381. Pitch Angle.—In any bevel gear the angle that the cone distance makes with the center line is called the pitch angle. Figure 343*a* represents two shafts running at right

angles with equal pitch cones. It will be noted that the pitch angle is one half of 90 deg. or 45 deg. It will be observed in Fig. 343*b* that in right-angle bevel gears, other than miter gears, the pitch angle of either the gear or the pinion cannot be 45 deg. and that the pitch angle depends on the relative pitch diameters of the gear and pinion. The pitch angle is one of the most important factors in bevel-gear calculations.

382. Pitch Diameter.—When speaking of the pitch diameter of a bevel gear, the diameter at the large end of the pitch cone is meant. As a matter of fact, the diameter at any given point in the pitch cone is the pitch diameter of *that part* of the gear, but in practice no thought or consideration is given to any other pitch diameter than the largest in the gear.

383. Face Width of Bevel Gear.—In making a bevel gear, the teeth are not cut on the whole pitch cone but only on a portion of it. The distance equal to the length of the tooth is called the *face width* of the bevel gear (Fig. 345). The ends of the teeth are spoken of as the "large end" and the "small end."

In practice the face width of the gear tooth is frequently shorter but never longer than one third of the cone distance. The dimension should be in sixteenths of an inch or greater, never in thirty-seconds or sixty-fourths.

384. Cone Distance (Apex Distance), Tooth Size and Shape.—In any bevel gear of whatever diameter, angle, or face, the teeth and spaces are largest at the largest diameter of the gear and decrease in size as the cone center of the original pitch cone is approached. If it can be imagined that teeth were cut along the whole pitch cone, halfway down the cone the teeth and spaces would be half as large as at the large end and all would vanish at the cone center.

Following this reasoning it will be clear that the sizes of bevel-gear-tooth parts, at the large end and at the small end, for example, are proportional to their respective cone distances. This proportion is used in practice (see Rule 46, page 466).

It will be understood that when the size of the tooth changes, the curve of the tooth also changes, and consequently it will be

impossible to cut a bevel gear accurately with a rotary cutter because the cutting edge has a fixed shape and curvature. However, a fairly accurate tooth shape can be milled by taking more than one cut, thus "trimming" the tooth as will be explained later.

The drawing (Fig. 345) will serve to illustrate the principles thus far outlined of a bevel gear built on a cone. Let the triangle *AOB* represent the original pitch cone with a pitch angle of 45 deg. and a pitch diameter of 3 in. Suppose it is decided to put 30 teeth on this gear and to have the face one third of the cone distance. The module (gear 3-in. pitch diameter, 30 teeth) is $\frac{1}{10}$ in., that is, the gear is 10*DP*. The cone distance *OC* is two thirds of the cone distance *OA* and consequently the module at the small end of tooth is two thirds of the module at the large end of tooth. That is, all the tooth parts, addendum, dedendum, thickness, at the small end of the tooth will be two thirds as large as corresponding parts of the tooth at the large end.

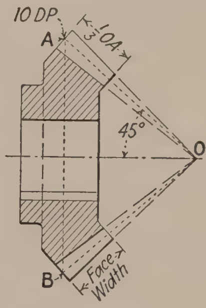


FIG. 345.

385. Laying Out Bevel Gears, Shafts at Right Angles.—Perhaps one of the best methods of becoming acquainted with bevel-gear parts and proportions is to lay out first a miter gear, then a gear and pinion. To get parts of miter gears to scale it is only necessary to draw one; to get the angles, proportions, etc., of the gear and pinion it is necessary to lay out both. It is usually best to make the drawings to a large scale if accuracy is required in measurements. In any event, in order to lay out bevel gears it is necessary to know *angle of shafts*, *relative velocities*, and *pitch of tooth*. Two examples with necessary directions follow (Figs. 346 and 347). Make these drawings full size or larger before proceeding further.

386. Laying Out Bevel Gears, Shafts Not at Right Angles.—Bevel gears with shafts at other than right angles (Fig. 343, *c* and *d*) may be drawn by method shown in Fig. 347, except that the pitch diameters will not be at right angles to each other.

For example, if the angle of the shafts *HO* and *XO* (as in Fig. 347) were 80 deg. instead of 90 deg., simply draw pitch diameter *AM* of pinion at an angle of 100 deg. with the pitch diameter *AB* of gear and proceed as for regular bevels. (The smaller the shaft angle, the greater the distance *OX*.)

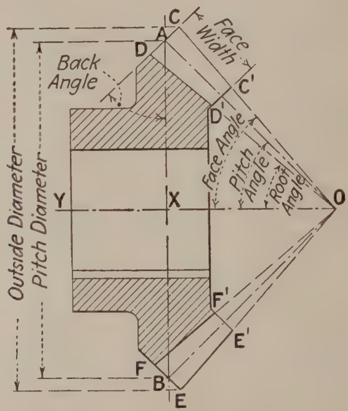


FIG. 346.—Directions for laying out miter gear. Gear selected, 4*DP*—20 teeth.

1. Draw center line *OY* and lay off *OX* equal to one half pitch diameter = 2½ in. ($PD = \frac{N}{DP} = \frac{20}{4} = 5$ in.; one half of 5 in. = 2½ in.).
2. Through *X* draw *AB* perpendicular to *OX* making *AX* and *BX* equal also to one half pitch diameter.
3. Draw *OA* and *OB*. These lines give size and shape of pitch cone, and each is called the *cone distance.* Either cone distance with *OX* forms the *pitch angle* of the gear. (In this gear, and all miter gears, pitch angle equals 45 deg.
4. At points *A* and *B* draw lines *CD* and *EF* perpendicular to the cone distance lines *OA* and *OB*. These lines form with *AB* the *back angle.* In all bevel gears the back angle is equal to the pitch angle.
5. On line *CD* lay off points *C* and *D* distant from *A* equal to the addendum and dedendum, respectively. (4*DP*, addendum = ¼ in.; *AC* = ¼ in.; dedendum = ¼ in. plus clearance = 0.289 in. *AD* = 0.289 in.)
6. Do the same at B. (*BE* = ¼ in.; *BF* = 0.289 in.)
7. Having decided on the *face width* (see paragraph 383) draw lines *C′D′* and *E′F′* parallel to *CD* and *EF*, respectively.
8. Draw *CO* and *EO*. These lines with *OX* form the *face angles* of the gear.
9. Draw *DO* and *FO*. These lines with *OX* form the *root angles* of the gear.

If the shaft angle is 110 deg., draw the pitch diameter *AM* at an angle of 70 deg. with pitch diameter *AB* and proceed as before.

The angle formed by the two *pitch diameters* will be just as many degrees less than 90 deg. as the shaft angle is over 90 deg., or just as many degrees over 90 deg. as the shaft angle is less than 90 deg.

387. Calculations for Bevel Gears.—The outside diameter, the face angle, the root angle, etc., may be obtained fairly close with a scale and protractor from a good drawing. They may be obtained also from tables of gear-tooth parts in handbooks, etc. These tables have been calculated by the use of rules, and in order to read the tables intelligently it is best to understand the rules. An example showing the calculations for a miter gear is given on page 466.

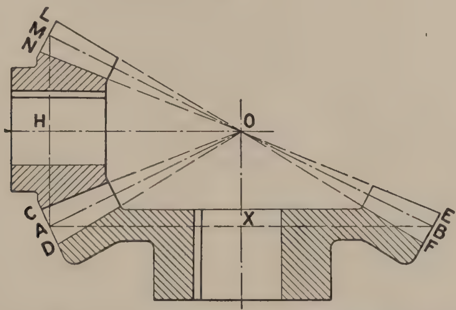


FIG. 347.—Directions for laying out bevel gears, shafts at right angles. Gears selected: Gear 4*DP*—24 teeth, pinion 12 teeth.

1. Draw center lines of shafts at right angles, intersecting at *O*.
2. Lay off *OH* equal to one half pitch diameter of gear (= 3 in.) and lay off *OX* equal to one half pitch diameter of pinion (= 1½ in.).
3. Through points *X* and *H* draw pitch diameters *AB* and *AM*, making *BX* = *AX* and *MH* = *AH*.
4. Draw *OA*, *OM*, and *OB*. These lines represent the pitch cones of the two gears. The point *O* of intersection of the lines *HO* and *XO* will also be the common point of intersection of all the lines *OL*, *ON*, *OC*, *OD*, *OE*, and *OF*, which are found and drawn the same as shown for miter gears (Fig. 346).

In order to calculate bevel gears, a working knowledge of some of the functions of right triangles must be had. If machinists realized how easily and quickly "shop trig" may be understood, more of them would spend a few hours and get this understanding.[1]

NOTE.—For trigonometric formulas and tables see pages 492 to 495.

[1] Any one of the following books will give the necessary information.

"American Machinists' Handbook," by Colvin and Stanley. McGraw-Hill Book Company, Inc., New York.

"Mathematics for Machinists," by Burnham. John Wiley & Sons, Inc., New York.

"Treatise on Gearing," Brown & Sharpe Mfg., Co., Providence, R. I.

388. Definitions and Rules, Bevel-gear Elements and Tooth Parts (Fig. 348).—These are arranged in alphabetical order. (Other gear terms common to both spur and bevel gears are defined beginning page 445.)

1. *Addendum.*—Same as for spur gear, equals 1 divided by the diametral pitch.
2. *Addendum angle* is the angle between the elements of the pitch cone and the face cone in a plane containing the axis of the gear.

RULE.—The tangent of the addendum angle equals the addendum divided by the cone distance.

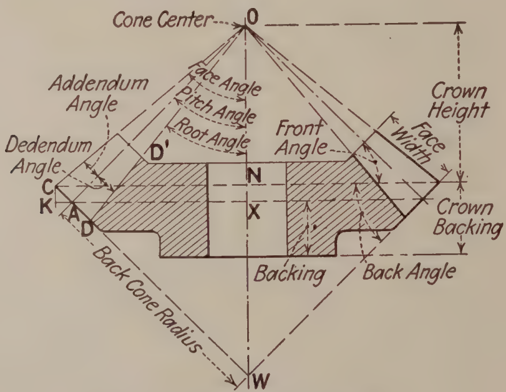


FIG. 348.—Parts of bevel gear.

3. *Angles.*—Addendum, back, dedendum, face, front, pitch, root, and shaft—see in alphabetical order according to name.
4. *Apex distance*, see cone distance.
5. *Back angle* is the angle between the plane of the pitch circle and a plane tangent to the large end of the tooth; equals the pitch angle.
6. *Back cone* is the cone generated by revolving the back-cone radius about the axis of the gear.
7. *Back-cone radius* is the distance perpendicular to the pitch surface from the pitch circle to the axis; equals cone distance times the tangent of the pitch angle.
8. *Backing* is the distance parallel to the axis from the pitch circle to the face (end) of the shoulder or hub. (Do not confuse with crown backing.)
9. *Bore diameter* is the diameter of the hole in the gear.
10. *Bottom angle*, see Root angle.
11. *Clearance.*—Same as for spur gear.

12. *Cone center* is the apex of the pitch cone.

13. *Cone distance* is the distance from the cone center to any point on the pitch circle; equals one half the pitch diameter divided by the sine of the pitch angle.

14. *Crown* is the circle formed by the intersection of the face cone and the back cone extended.

15. *Crown backing* is the distance, parallel to the axis, from the crown to the shoulder or hub end. (Do not confuse with *backing.*)

16. *Crown height* is the distance, parallel to the axis, from the cone center to the crown of the gear; equals the product of the cone distance times the cosine of the pitch angle, *minus* the product of the addendum times the sine of the pitch angle.

17. *Decrement angle,* see Dedendum angle.

18. *Dedendum.*—Same as for spur gear (usually 1.157 divided by the diametral pitch).

19. *Dedendum angle* is the angle between elements of the pitch cone and root cone in a plane containing the axis of the gear. The tangent of the dedendum angle equals the dedendum divided by cone distance.

20. *Diameter increment* is the amount added to the pitch diameter to obtain the outside diameter; equals two times the addendum multiplied by the cosine of the pitch angle.

(It will be observed in Fig. 348 that NC, the outside radius, is greater than XA, the pitch radius, by the length of KA, and *not* by the length of CA, the addendum. Do not add "two addendums" to the pitch diameter of a bevel gear.)

21. *Diametral pitch*—Same as for spur gears; equals number of teeth divided by the pitch diameter.

22. *Face angle* is the angle between an element of the face cone and its axis; equals pitch angle plus addendum angle.

23. *Face cone* is the right circular cone whose elements contain the top lands of the gear.

24. *Face width* is the width of the pitch surface.

25. *Front angle* is the angle between the plane of the pitch circle and a plane tangent to the small end of the tooth; equals the pitch angle.

26. *Heel* is a portion of the tooth at the large end; *toe* on the small end.

27. *Increment angle,* see Addendum angle.

28. *Module,* see page 443.

29. *Mounting distance* is the distance, parallel to the axis, from the cone center to the shoulder or hub end against which the gear is mounted; equals crown backing plus crown height.

30. *Outside diameter* is the diameter of the circle which contains the tops of the teeth; equals pitch diameter plus diameter increment.

31. *Pitch angle* is the angle between an element of the pitch cone and its axis. With shafts at right angles, the tangent of pitch angle of the

gear equals number of teeth in gear divided by number of teeth in pinion, and pitch angle of *pinion* equals 90 deg. minus pitch angle of gear.

32. *Pitch circle* is the circle formed by the intersection of the pitch cone and a plane perpendicular to the axis. *Circumference* of pitch circle equals pitch diameter times 3.1416.

33. *Pitch cone* is the cone generated by revolving the cone-distance line about the axis of the gear.

34. *Pitch diameter* is the diameter of the pitch circle; equals the number of teeth divided by the diametral pitch.

35. *Root angle* is the angle between an element of the root cone and its axis; equals pitch angle minus the dedendum angle.

36. *Root circle* is the circle containing the bottoms of the tooth spaces.

37. *Root cone* is the right circular cone whose elements contain the bottoms of the tooth spaces.

38. *Root diameter* is the diameter of the root circle.

39. *Shaft angle* is the included angle between the shafts upon which a pair of mating gears are to operate; equals the sum of the pitch angles of the two gears.

41. *Thickness*, chordal, circular, same definitions as for spur gears.

42. *Toe* is a portion of the small end of the tooth—*heel* on the larger end.

43. *Undercut*, see definition 35; page 447.

44. *Virtual number of teeth* is the number of teeth of a given pitch which would be contained in the *virtual pitch circle* whose radius is the back-cone radius. See paragraph 391, page 468.

Rule.—Number of teeth for which to select the cutter for a bevel gear equals the number of teeth in the bevel gear divided by the cosine of the pitch angle.

45. *Size of tooth parts at large end:* Same as for spur gear of same pitch.

46. *Size of tooth parts at small end:* Divide the cone distance of small end by the cone distance of large end and multiply the respective tooth parts of large end by the quotient.

389. Example Showing Calculations for Miter Gear.—Gear selected, $4DP$, 20 teeth (see Fig. 346). Use rules (paragraph 388) as indicated by the numbers.

1. Addendum $= \frac{1}{DP} = \frac{1}{4}$ in.

18. Dedendum $= \frac{1.157}{DP} = \frac{1.157}{4} = 0.289$ in.

34. Pitch diameter $= \frac{N}{DP} = \frac{20}{4} = 5$ in.

31. Pitch angle $= 45$ deg. (45 deg. always in miter gears).

13. Cone distance = ½ pitch diameter divided by the sine of the pitch angle = 2.5 in. ÷ 0.707 = 3.536 in.

20. Diameter increment = two times the addendum multiplied by the cosine of the pitch angle = 2 × ¼ × 0.707 = 0.3535 in.

30. Outside diameter = pitch diameter plus diameter increment = 5 in. plus 0.3535 in. = 5.3535 in.

2. Addendum angle: Tangent of addendum angle equals addendum divided by the cone distance, equals ¼ in. ÷ 3.536 = 0.0707, which is tangent of angle 4°3′. Therefore addendum angle is 4°3′.

19. Dedendum angle: Tangent of dedendum angle equals dedendum divided by cone distance, equals 0.289 ÷ 3.536 = 0.0817, which is tangent of angle 4°40′. Therefore dedendum angle is 4°40′.

22. Face angle equals pitch angle plus addendum angle 45° plus 4°3′ = 49°3′.

35. Root angle (cutting angle) equals the pitch angle minus the dedendum angle = 45° minus 4°40′ = 40°20′.

45. Size of tooth parts on large end are same as for spur gear of the same pitch.

46. Size of tooth parts at the small end: As one third of the cone distance (3.536 in.) is 1.179 in., let the face width of the teeth measure 1⅛ in. (See paragraph 383, page 460). Then

$$3.536 \text{ in. minus } 1.125 \text{ in.} = 2.411 \text{ in.,}$$

which is the cone distance of the small end of teeth.

$$2.411 \div 3.536 = 0.682,$$

therefore multiply the parts of the tooth at the large end by 0.682 to obtain the sizes of the corresponding tooth parts at the small end. Addendum equals ¼ × 0.682 = 0.170 in.

$$\text{Whole depth equals } \frac{2.157}{4} \times 0.682 = 0.367 \text{ in.}$$

$$\text{Circular thickness equals } \frac{1.57}{4} \times 0.682 = 0.267 \text{ in.}$$

44. Number of teeth for which to select the cutter for miter gear equals $\frac{\text{number of teeth}}{0.707} = \frac{20}{0.707} = 28$. (This is the same number of cutter as for a spur gear of 28 teeth, therefore the No. 4 bevel-gear cutter is used—see paragraph 391).

390. Cutting a Bevel Gear in a Milling Machine.—As previously stated, it is impossible to cut an *accurate* bevel gear in a milling machine. It often happens, however, that a

bevel gear may be wanted in a hurry, or that an extremely accurate gear is not required, and it is then convenient to know how to mill one (Fig. 350).

391. Selecting the Cutter.—In the study of spur gearing it has been learned that the same "form" of gear cutter, that is the same number of cutter, is not used to cut a gear of 20 teeth that is used to cut a gear of 120 teeth. This is because the pitch surface of the 120-tooth gear has a longer radius of curvature than the 20-tooth gear, in other words, it is nearer straight.

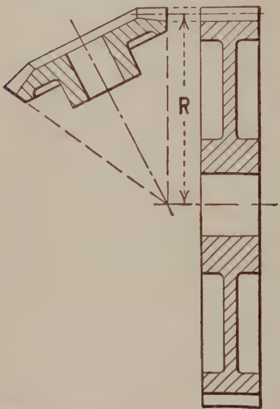


FIG. 349.—Radius of rolling pitch surface.

Bevel-gear cutters are made in sets similar to spur-gear cutters with the same range of numbers of teeth to each cutter (see page 452). Bevel-gear cutters have a *curve of cutting edge* that is right for the large end of the tooth, but they are thinner than spur-gear cutters because they must pass through the spaces at the small end of the teeth. There is one feature in the selection of a bevel-gear cutter which at first seems difficult to understand; the cutter is not selected for the number of teeth in the bevel gear itself, but for a spur gear having a *pitch radius* equal to the *back-cone radius* of the bevel gear. For example, in Fig. 349 the number of cutter to select for the bevel gear would be determined by the number of teeth in the spur gear. The reason for this may be explained as follows:

The radius of the pitch surface of a spur gear is the same as the radius of the pitch circle of that gear, *but the radius of the rolling pitch surface of a bevel gear is longer than the radius of the pitch circle of that bevel gear.*[1] Thus in Fig. 349

[1] The difference between the curvature of the *rolling pitch surface* of a bevel gear and the curvature of the *pitch circle* of that gear may be easily seen. Select a bevel gear (as large as 10 or 12 in. in diameter is best) lay a piece of paper along the outer edge of the teeth in close contact against the edge of five or six teeth and rub it to make an imprint

the back-cone radius of the bevel gear is equal to the radius of curvature of the spur gear.

The back-cone radius is not used directly in *calculating* the cutter to use (see rule below), but if a good drawing is furnished, it may be practically useful in determining the cutter, or in checking the calculation by the rule.

RULE.—Number of teeth for which to select the cutter equals the number of teeth in the bevel gear divided by the cosine of the pitch angle.

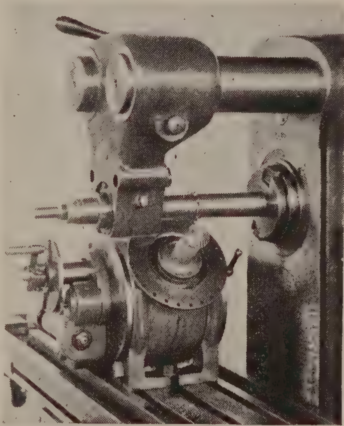


FIG. 350.—Cutting a bevel gear in a milling machine.

392. Order of Operations. Let it be required to cut a bevel gear. The following directions in general will apply to any bevel gear, but select, for an example, say a cast-iron gear of 24 teeth, 4*DP* (Fig. 347). The data necessary to cut this bevel gear should be furnished with the order or on the drawing, but may be calculated, as previously explained. (See rules, paragraph 388.) The sizes are as follows: $DP = 4$; whole depth = 0.539 in.; circular thickness = 0.393 in.; addendum = 0.250 in. For small end of tooth, thickness = 0.267 in.; addendum = 0.170 in. The root angle (cutting angle) is 50°10′. Use No. 3 cutter.

Important Precaution.—In any milling-machine indexing operation, the backlash or lost motion in the index-head worm and wormwheel, and in the feed screws, is a most serious consideration. **Do not neglect the lost motion.**

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of the teeth on the paper. Trim this paper to the pitch line of these teeth, and it will be cut to approximately the *curvature* of the *rolling pitch surface* of the gear. If, now, the paper is held at right angles to the center line of shaft, with the curve cut on the paper as nearly coincident with the curve of the pitch circle of the gear as possible, the difference between these curves will be apparent. The nearer the bevel gear approaches the spur gear, that is, the less bevel it has, the less this difference.

1. Check the measurements of the blank, especially the outside diameter and the face angle.

2. For 24 teeth, set the index pin in a circle divisible by 3. The largest circle is best to permit of finer adjustment for reasons hereafter explained (10). Set the sector to two thirds of one turn.

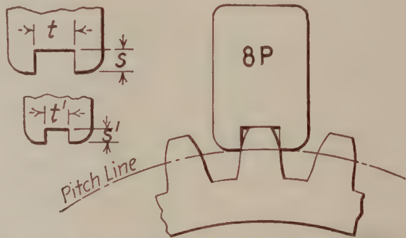


Fig. 351.—Gear-tooth gauges and illustration of their use: t, thickness at large end; s, addendum at large end; t', thickness at small end; s', addendum at small end.

3. Set the dividing head to the root angle (equals 59°10′).

4. Being careful that spindle, arbor, collars, and cutter are clean and that arbor runs true, set the cutter on the arbor so the direction of the cut will be away from the dividing-head spindle. Have the cutter as near the machine spindle as practicable and bring the work *central* under the cutter.

5. Adjust the table until the revolving cutter just touches the gear blank at the *outside* diameter.

6. Raise the table the whole depth (0.539 in.) and take a cut (perhaps a roughing cut will be advisable). Index for one tooth and take another cut.

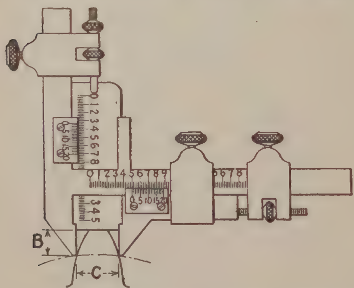


Fig. 352.—Gear tooth vernier. An almost indispensable tool if much gear work is done. Measures the chordal thickness C when set for the correct addendum B.

7. Measure the thickness of tooth, preferably with gear-tooth caliper (Fig. 352), at large end and at small end.

8. Subtract the finished thickness of tooth (t = 0.393 in.; t' = 0.262) from the thickness as measured, and divide by 2 to

know how much must be "trimmed" from each side (*a*, Fig. 353). Take *both* halves away and the finished size will remain; take one half away and the size of tooth *when one side of the tooth is finished* will remain.

NOTE.—There now are two spaces with a tooth between; the depth of tooth is established and the curve of the cutter is right for the large end, but since the thickness of the cutter is about right for the finished space at the small end, the thickness of tooth at the large end is altogether too great. Since the curve of the cutter is correct for the large end of the tooth, the shape of the tooth at the small end is not right.

The job of cutting a bevel gear in a milling machine is to get the correct *thickness* of tooth, *at the pitch line*, at *both* ends of tooth by trimming both sides of the tooth and then to file the small end to the correct curve (Fig. 353).

In any motion of a wheel on its axis a point on the rim passes through a greater arc, a greater distance, than a point on the hub. So, by the same principle, in any movement of a bevel gear or bevel-gear blank on its axis, the large end moves further than the small end. That is, if the gear blank is revolved a very little (if the index pin is removed and advanced one or two holes on the plate), the tooth will be cut thinner, and a little more metal will be removed from the large end than from the small end, *but*, as it happens, *not enough in proportion.* If the gear is rotated, say, 5 or 6 holes in the 39 circle, the large end may be right; but, the small end will be too thin. To avoid this, offset the blank, that is, move the table of the milling machine crosswise, bringing the gear tooth *away* from the cutter, and then *rotate* the gear tooth toward the cutter. This has the effect of taking more in proportion off the large end than off the small end.

To continue with the directions:

9. With blue-vitriol, paint the spaces cut; *take up the lost motion* in the cross-feed screw; set the dial at *O*, and, for a trial, offset the table about *one seventh* the thickness of the tooth at the large end.

10. Pull out the index pin and rotate the blank until the large end of the tooth touches the cutter, and then *very carefully* (rotating the blank one hole (see 2) in index plate for each cut) trim the side of the tooth until the blue vitriol is nearly all cut off toward the small end.

11. Measure the thickness at the large end, and at the small end for sizes "*when one side is finished*" (see 8). If there

remains more metal to be cut from the large end than from the small end, the blank must be offset a little more and the tooth trimmed again.

12. Having obtained the position of the blank to trim one side of the tooth for finish, *note the amount of offset and the number of holes which the blank was rotated.*

13. Index for the next tooth, take a cut, and so on, all around the gear blank, and there will be 24 teeth with *one side finished.*

NOTE.—In a cast-iron gear of 5 pitch or larger or in a steel gear of 8 pitch or larger, it is usually advisable to take a *central* roughing cut or "stocking" cut before "trimming" either side.

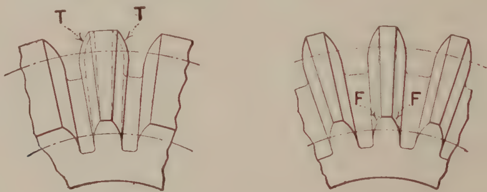


FIG. 353.—(*a*) Shows at *T* when the tooth is trimmed with the cutter; (*b*) shows at *F* when the tooth is filed.

14. Having finished one side of each tooth, offset the gear the same amount from center, being careful about the backlash, *in the opposite direction*, rotate the blank as many holes as noted (see 12) *in the opposite direction*, and carefully checking the measurements of first tooth (to finished size, see 8) proceed to trim the other side of each tooth.

15. File the small ends of teeth to size, as indicated at the lines marked *F* in Fig. 353.

NOTE.—The amount of offset is from one seventh to one sixth of the thickness of the tooth at large end. In the above gear, 4*DP* – 24 teeth, it is about 0.060 in. In a 12*DP* 40-tooth *miter* gear it is about 0.018 in. In a pair of bevel gears, 8*DP*, gear 24 teeth, pinion 12 teeth, offset for gear is 0.030 in., and for pinion 0.021 in.

Too little offset leaves large end too thin.

Questions on Bevel Gears

1. Look up the definitions of the words apex, cone, frustum, truncated.

2. Explain the following statement: A bevel gear may be said to be built on the frustum of an imaginary or theoretical cone.

3. Pitch in machine-shop talk means primarily a distance and has come in gear work to denote a given size. In spur gears the teeth are built or "sized" or "pitched" on the pitch cylinder and the teeth of bevel gears are pitched on pitch cones. What do you understand by the pitch cylinder being the working size or effective size of the spur gear and the pitch cone being the working size of the bevel gear?

4. Where is the center line of a bevel gear? The pitch diameter? The apex distance?

5. What is the center angle? Face angle? Edge angle?

6. Is the face angle equal to the center angle? How do center angle and edge angle compare in size?

7. In shop drawings for turning bevel gears is it necessary to dimension the face angle? What angle does the face of the tooth make with the edge?

8. In order to turn up a bevel-gear blank in a lathe, is it necessary to know the outside diameter at large end of tooth? At small end?

9. What is the difference between the face of a gear *tooth* and the face of a *gear?*

10. Explain why and how the face of a bevel gear should be dimensioned in a shop drawing.

11. Did you have any particular trouble in laying out the bevel gears?

12. Is the outside diameter of a bevel gear "two addendums larger than the pitch diameter?"

13. What do you understand by diameter increment?

14. Angle increment is sometimes called "addendum angle," and angle decrement the "dedendum angle." Can you explain this?

15. What is the cutting angle? Clearance angle? Is it always necessary to know the clearance angle? Explain.

16. Extreme care must be taken in setting any swiveling device, for example, compound rest in the lathe or dividing head in milling machine, not to cut the complement of the angle instead of the angle. This is especially true when the angle is only a few degrees more or less than 45 deg. How do you explain the reason for this precaution?

17. In cutting a miter gear, $4DP$, 20 teeth, a No. 4 bevel-gear cutter marked "26 to 34 teeth" is used (see 44, paragraph 466). How do you account for this?

18. Do you feel confident that you can intelligently turn a bevel-gear blank and if occasion arises cut it in the milling machine?

APPENDIX

List of Tables

Table 1.—Mensuration

Area

Parallelogram	= base × perpendicular height.
Trapezoid	= half the sum of the parallel sides × perpendicular height.
Triangle	= base × half perpendicular height.
Circle	= diameter squared × 0.7854 or circumference squared × 0.07958.
Sector of a circle	= length of arc × half radius.
Segment of a circle	= { area of sector of equal radius—triangle when segment is less, and + area of triangle when segment is greater than the semicircle.
Side of square of equal area as circle	= diameter × 0.8862 or circumference × 0.2821.
Diameter of a circle of equal area as square	= side × 1.1284.
Parabola	= base × ⅔ height.
Ellipse	= long diameter × short diameter × 0.7854.
Regular polygon	= sum of sides × half perpendicular distance from center to sides.
Cylinder	= circumference × height + area of both ends.
Sphere	= diameter squared × 3.1416, or diameter × circumference.
Segment of sphere	= height of segment × circumference of sphere of which it is a part + area of base.
Pyramid or cone	= circumference of base × one-half slant height + area of base.
Frustum of pyramid	= sum of circumference at both ends × one-half slant height + area of both ends.

Length

Circumference of circle = diameter × 3.1416.
Diameter of circle = circumference × 0.3183.
Side of square of equal periphery as circle = diameter × 0.7854.
Diameter of circle of equal periphery as square = side × 1.2732.
Side of an inscribed square = diameter of circle × 0.7071.
Length of arc = number of degrees × diameter × 0.008727.
Circumference of circle whose diameter is 1 = 3.14159265.
English statute miles = lineal feet × 0.00019.
English statute miles = lineal yards × 0.000568.

Solid Contents

Prism or cylinder = area of end × length.
Sphere = cube of diameter × 0.5236.

Segment of sphere = (height squared + three times the square of radius of base) × (height × 0.5236).

Side of an equal cube = diameter of sphere × 0.806.

Length of an equal cylinder = diameter of sphere × 0.6667.

Pyramid or cone = area of base × 13 altitude.

Frustum of cone = {add to the product of the two diameters the square of the large diameter and the square of the small diameter; multiply the sum by 0.7854 and the product by ⅓ the altitude.

TABLE 2.—CUTTING SPEEDS LATHE WORK, DRILLS, MILLING CUTTERS

FORMULAS: $CS = 0.26D \times$ r.p.m.; and R.p.m. $= \dfrac{CS}{0.26D}$

Dia.	Cutting speeds in feet per minute																
	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
	Revolutions per minute																
¼	306	458	611	764	916	1070	1222	1376	1528	1681	1833	1986	2139	2292	2462	2615	2780
⅜	204	306	407	509	612	712	814	916	1019	1120	1222	1324	1426	1528	1632	1735	1836
½	153	229	306	382	458	534	612	688	764	840	917	993	1070	1146	1221	1298	1374
⅝	122	183	244	306	366	428	488	550	611	672	733	794	856	917	976	1036	1098
¾	102	153	204	255	306	356	408	458	509	560	611	662	713	764	816	867	918
⅞	87	131	175	218	262	306	350	392	437	480	524	568	611	655	699	742	786
1	76	115	153	191	230	268	306	344	382	420	458	497	535	573	611	649	687
1⅛	68	102	136	170	204	238	272	306	340	373	407	441	475	509	542	576	610
1¼	61	92	122	153	184	214	244	274	306	336	367	397	428	458	489	520	551
1⅜	56	83	111	139	167	194	222	250	278	306	333	361	389	417	444	472	500
1½	51	76	102	127	152	178	204	228	255	280	306	331	357	382	407	433	458
1⅝	47	71	94	118	141	165	188	212	235	259	282	306	329	353	377	400	423
1¾	44	65	87	109	130	152	174	196	218	240	262	284	306	327	349	371	393
1⅞	41	61	82	102	122	143	163	183	204	224	244	265	285	306	326	346	366
2	38	57	76	95	114	134	152	172	191	210	229	248	267	287	306	324	344
2⅛	36	54	72	90	108	126	144	162	180	198	216	234	252	270	288	306	323
2¼	34	51	68	85	102	119	136	153	170	187	204	221	238	255	272	289	306
2⅜	32	48	64	80	97	112	129	145	161	177	193	210	225	241	257	273	290
2½	31	46	61	76	92	106	122	134	153	168	183	199	214	229	244	260	275
2⅝	29	44	58	73	88	102	117	130	146	160	175	189	204	218	233	248	262
2¾	28	42	56	70	83	97	111	125	139	153	167	181	194	208	222	236	250
2⅞	27	40	53	67	80	93	106	119	133	146	159	173	186	199	213	226	239
3	25	38	51	64	76	90	102	114	127	140	153	166	178	191	204	216	229

TABLE 3.—PLANER CUTTING SPEEDS

Actual number of feet of metal cut per minute with given forward speeds and various return speeds

Forward Cutting Speed in Feet per Minute	Return Speed						
	2 to 1	3 to 1	4 to 1	5 to 1	6 to 1	7 to 1	8 to 1
20	13.3	15.	16	16.66	17.14	17.5	17.76
25	16.6	18.75	20	20.83	21.42	21.87	22.16
30	20.	22.5	24	25.	25.71	26.25	26.56
35	23.3	26.25	28	29.16	30.	30.62	31.04
40	26.6	30.	32	33.33	34.28	35.	35.52
45	30.	33.75	36	37.5	38.56	39.37	40.
50	33.3	37.5	40	41.66	42.84	43.75	44.48
55	36.6	41.25	44	45.83	47.12	48.12	48.95
60	40.	45.	48	50.	51.42	52.50	53.43
65	43.3	48.75	52	54.16	55.70	56.87	57.91
70	46.6	52.5	56	58.33	60.	61.25	62.3
75	50.	56.25	60	62.5	64.28	66.62	66.71

The table shows clearly that a slight increase in cutting speed is better than high return speed. A 25-ft. forward speed at 4:1 return is much better than 8:1 return with 20-ft. forward speed. Economical planer speeds are given below (Cincinnati Planer Co.).

Cast-iron roughing, 40 to 50 ft., finishing, 20 to 25 ft.; steel-casting and wrought-iron roughing, 30 to 35 ft., finishing, 20 ft.; bronze and brass, 50 to 60 ft.; machinery steel, 30 to 35 ft.

TABLE 4.—DIAGONALS OF HEXAGONS AND SQUARES

Across flats	Across corners		Across flats	Across corners		Across flats	Across corners	
	Hexagon	Squares		Hexagon	Squares		Hexagon	Squares
1/16	.072	.088	1 3/8	1.587	1.944	2 11/16	3.103	3.800
1/8	.144	.177	1 7/16	1.659	2.032	2 3/4	3.175	3.889
3/16	.216	.265	1 1/2	1.732	2.121	2 13/16	3.247	3.979
1/4	.288	.353	1 9/16	1.804	2.209	2 7/8	3.319	4.065
5/16	.360	.441	1 5/8	1.876	2.298	2 15/16	3.391	4.154
3/8	.432	.530	1 11/16	1.948	2.386	3	3.464	4.242
7/16	.505	.618	1 3/4	2.020	2.470	3 1/16	3.536	4.331
1/2	.577	.707	1 13/16	2.092	2.563	3 1/8	3.608	4.419
9/16	.649	.795	1 7/8	2.165	2.651	3 3/16	3.680	4.507
5/8	.721	.883	1 15/16	2.237	2.740	3 1/4	3.752	4.596
11/16	.793	.972	2	2.309	2.828	3 5/16	3.824	4.684
3/4	.865	1.060	2 1/16	2.381	2.916	3 3/8	3.897	4.772
13/16	.938	1.149	2 1/8	2.453	3.005	3 1/2	4.041	4.949
7/8	1.010	1.237	2 3/16	2.525	3.093	3 5/8	4.185	5.126
15/16	1.082	1.325	2 1/4	2.598	3.182	3 3/4	4.330	5.303
1	1.155	1.414	2 5/16	2.670	3.270	3 7/8	4.474	5.480
1 1/16	1.226	1.502	2 3/8	2.742	3.358	4	4.618	5.656
1 1/8	1.299	1.591	2 7/16	2.814	3.447	4 1/8	4.763	5.833
1 3/16	1.371	1.679	2 1/2	2.886	3.535	4 1/4	4.904	6.010
1 1/4	1.443	1.767	2 9/16	2.958	3.623	4 3/8	5.051	6.187
1 5/16	1.515	1.856	2 5/8	3.031	3.712	4 1/2	5.196	6.363

Diagonal of hexagon equals 1.155 times distance across flats.
Diagonal of square equals 1.414 times distance across flats.
Largest square that can be inscribed in circle equals 0.707 times the diameter.
Largest hexagon that can be inscribed in circle equals 0.866 times the diameter.
Largest square that can be cut on cylinder = dia. × 0.707.
Largest hexagon that can be cut on cylinder = dia. × 0.866.

TABLE 5.—WEIGHTS OF FLAT BAR STEEL PER LINEAR FOOT

	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2	1 3/4	2	2 1/4	2 1/2	2 3/4	3	3 1/2	4	5	6
1/8	.213	.266	.320	.372	.426	.479	.530	.585	.640	.745	.850	.955	1.07	1.18	1.28	1.49	1.70	2.13	2.56
3/16	.319	.399	.480	.558	.639	.718	.790	.878	.960	1.12	1.28	1.43	1.60	1.76	1.92	2.24	2.55	3.20	3.83
1/4	.425	.533	.640	.743	.852	.958	1.06	1.17	1.28	1.49	1.70	1.91	2.13	2.34	2.56	2.98	3.40	4.26	5.11
5/16	.531	.665	.800	.929	1.06	1.20	1.33	1.46	1.60	1.86	2.13	2.39	2.66	2.92	3.19	3.72	4.25	5.32	6.38
3/8	.638	.798	.960	1.12	1.28	1.43	1.59	1.75	1.91	2.23	2.55	2.87	3.20	3.51	3.83	4.46	5.10	6.40	7.66
7/16	.744	.931	1.12	1.30	1.49	1.67	1.86	2.05	2.23	2.60	2.98	3.35	3.72	4.09	4.46	5.21	5.95	7.44	8.92
1/2	..	1.07	1.28	1.49	1.70	1.91	2.13	2.34	2.55	2.98	3.40	3.83	4.26	4.68	5.10	5.96	6.80	8.52	10.20
9/16	..	1.20	1.44	1.67	1.91	2.15	2.39	2.63	2.87	3.35	3.83	4.30	4.78	5.26	5.74	6.69	7.65	9.56	11.50
5/8	..	..	1.60	1.86	2.12	2.39	2.66	2.92	3.19	3.72	4.26	4.79	5.32	5.86	6.39	7.44	8.52	10.64	12.78
11/16	..	..	1.76	2.04	2.34	2.63	2.92	3.22	3.51	4.09	4.68	5.26	5.84	6.43	7.01	8.18	9.35	11.70	14.00
3/4	..	..	..	2.23	2.55	2.86	3.19	3.50	3.83	4.46	5.10	5.74	6.40	7.02	7.65	8.92	10.20	12.80	15.30
13/16	..	..	..	2.41	2.76	3.11	3.45	3.80	4.14	4.83	5.53	6.22	6.91	7.60	8.29	9.67	11.10	13.80	16.60
7/8	..	..	..	..	2.98	3.34	3.72	4.09	4.46	5.21	5.96	6.70	7.46	8.19	8.94	10.42	11.92	14.92	17.88
15/16	..	..	..	..	3.19	3.59	3.98	4.38	4.78	5.58	6.38	7.17	7.97	8.77	9.56	11.20	12.80	15.90	19.10
1	..	..	..	..	..	3.82	4.25	4.68	5.10	5.96	6.80	7.66	8.52	9.36	10.20	11.92	13.60	17.04	20.40
1 1/8	..	..	..	..	..	..	4.78	5.27	5.74	6.71	7.65	8.61	9.59	10.54	11.48	13.41	15.30	19.17	22.95
1 1/4	..	..	..	..	..	..	..	5.85	6.38	7.45	8.50	9.57	10.65	11.71	12.76	14.90	17.00	21.30	25.61
1 1/2	..	..	..	..	..	..	..	7.02	7.67	8.94	10.20	11.49	12.78	14.04	15.30	17.88	20.40	25.56	30.

TABLE 6.—WEIGHTS OF STEEL AND WROUGHT IRON

Dia. or Distance Across Flats	STEEL				IRON	
	Weight per Foot				Weight per Foot	
	Round	Square	Hexagon	Octagon	Round	Square
$\frac{1}{16}$	.010	.013	.012	.011	.010	.013
$\frac{1}{8}$	.042	.053	.046	.044	.041	.052
$\frac{3}{16}$	.094	.119	.103	.099	.092	.117
$\frac{1}{4}$	.167	.212	.185	.177	.164	.208
$\frac{5}{16}$	.261	.333	.288	.277	.256	.326
$\frac{3}{8}$	.375	.478	.414	.398	.368	.469
$\frac{7}{16}$	.511	.651	.564	.542	.501	.638
$\frac{1}{2}$	.667	.850	.737	.708	.654	.833
$\frac{9}{16}$	.845	1.076	.932	.896	.828	1.055
$\frac{5}{8}$	1.043	1.328	1.151	1.107	1.023	1.302
$\frac{11}{16}$	1.262	1.608	1.393	1.331	1.237	1.576
$\frac{3}{4}$	1.502	1.913	1.658	1.584	1.473	1.875
$\frac{13}{16}$	1.763	2.245	1.944	1.860	1.728	2.201
$\frac{7}{8}$	2.044	2.603	2.256	2.156	2.004	2.552
$\frac{15}{16}$	2.347	2.989	2.591	2.482	2.301	2.930
1	2.670	3.400	2.947	2.817	2.618	3.333
$1\frac{1}{16}$	3.014	3.838	3.327	3.182	2.955	3.763
$1\frac{1}{8}$	3.379	4.303	3.730	3.568	3.313	4.219
$1\frac{3}{16}$	3.766	4.795	4.156	3.977	3.692	4.701
$1\frac{1}{4}$	4.173	5.312	4.605	4.407	4.091	5.208
$1\frac{5}{16}$	4.600	5.857	5.077	4.858	4.510	5.742
$1\frac{3}{8}$	5.049	6.428	5.571	5.331	4.950	6.302
$1\frac{7}{16}$	5.518	7.026	6.091	5.827	5.410	6.888
$1\frac{1}{2}$	6.008	7.650	6.631	6.344	5.890	7.500
$1\frac{9}{16}$	6.520	8.301	7.195	6.905	6.392	8.138
$1\frac{5}{8}$	7.051	8.978	7.776	7.446	6.913	8.802
$1\frac{11}{16}$	7.604	9.682	8.392	8.027	7.455	9.492
$1\frac{3}{4}$	8.178	10.41	9.025	8.635	8.018	10.21
$1\frac{13}{16}$	8.773	11.17	9.682	9.264	8.601	10.95
$1\frac{7}{8}$	9.388	11.95	10.36	9.918	9.204	11.72
$1\frac{15}{16}$	10.02	12.76	11.06	10.58	9.828	12.51
2	10.68	13.60	11.79	11.28	10.47	13.33
$2\frac{1}{8}$	12.06	15.35	13.31	12.71	11.82	15.05
$2\frac{1}{4}$	13.52	17.22	14.92	14.24	13.25	16.88
$2\frac{3}{8}$	15.07	19.18	16.62	15.88	14.77	18.80
$2\frac{1}{2}$	16.69	21.25	18.42	17.65	16.36	20.83
$2\frac{5}{8}$	18.40	23.43	20.31	19.45	18.04	22.97
$2\frac{3}{4}$	20.20	25.71	22.29	21.28	19.80	25.21
$2\frac{7}{8}$	22.07	28.10	24.36	23.28	21.64	27.55
3	24.03	30.60	26.53	25.36	23.56	30.00
$3\frac{1}{8}$	26.08	33.20	28.78	27.50	25.57	32.55
$3\frac{1}{4}$	28.20	35.92	31.10	29.28	27.65	35.21
$3\frac{3}{8}$	30.42	38.78	33.57	32.10	29.82	37.97
$3\frac{1}{2}$	32.71	41.65	36.10	34.56	32.07	40.83
$3\frac{5}{8}$	35.09	44.68	38.73	37.05	34.40	43.80
$3\frac{3}{4}$	37.56	47.82	41.45	39.68	36.82	46.88
$3\frac{7}{8}$	40.10	51.05	44.26	42.35	39.31	50.05
4	42.73	54.40	47.16	45.12	41.89	53.33

WIRE GAGES AND SHEET METAL GAGES

Considerable confusion exists in regard to the gage numbers or the decimal equivalent of the gage numbers when ordering wires and sheets of the various metals, owing to the fact that there are so many gages listed in the tables given in handbooks, catalogues, text books, etc. Fortunately most of these older standards are obsolete or practically obsolete and only a few are now generally accepted and used in the trade. These are listed in Table 7.

Steel Wire Gage, formerly called the Washburn & Moen Gage, and also the American Steel & Wire Co. Steel Wire Gage, is the standard gage for steel and iron wire excepting music wire, see "Music Wire Gage," and drill rods, see "Stubs' Steel Wire Gage."

The American Wire Gage, also known as the *Brown & Sharpe* gage, is the generally accepted standard for copper wire (other than telephone and telegraph wire, see British Imperial Standard Wire Gage), brass wire, german silver wire, and also for the thickness of *sheets* of these materials.

The A. S. & W. Co. New Music Wire Gage is regarded as standard in the United States, the older Washburn & Moen Music Wire Gage being obsolete. Foreign music wires are sized according to the respective makers gages.

Music steel spring wire or "music wire" or "piano wire" is the best quality of steel wire and has, as noted, its own particular gage. Nos. 13 to 27 inclusive are used in pianos, some of the smaller sizes in other musical instruments. It is a tough wire of great tensile strength and resilience without extreme hardness. It is particularly useful for making springs since it does not have to be hardened and tempered. Do not confuse music wire with spring wire. *Spring Wire* is made to the Steel Wire Gage. It may be obtained with any desired carbon content for the purpose desired but is not as high grade as music steel spring wire.

The Stubs' Steel Wire Gage is commonly used in this country as well as in England for measuring drill rods. Do not get the Birmingham or Stubs' Iron Wire Gage confused with Stubs' Steel Wire Gage.

The Birmingham or *Stubs' Iron Wire Gage* (B. W. gage) was formerly used in the United States and in Great Britain to designate soft steel and iron wire. It is the gage used for iron telephone and telegraph wire, but for gaging other iron and steel wire, has been superseded to a great extent in Great Britain by the British Imperial Gage and in the United States by the Steel Wire Gage.

British Imperial Standard Wire Gage is now the standard gage of Great Britain. It is used by the American Telephone and Telegraph Co. as a gage for copper telephone and telegraph wire and is referred to as the New British Standard (N. B. Std.).

RÉSUMÉ

WIRES:

- For steel wire, use Steel Wire Gage.
- For copper telephone or telegraph wire, use British Imperial Standard Gage. For iron telephone or telegraph wire use Birmingham gage.
- For copper, brass, and german silver wire, use American (Brown & Sharpe) gage.
- For music wire use A. S. & W. *new* Music Wire Gage, and for imported music wire use gage of maker.
- For drill rod use Stubs' Steel Wire gage.

SHEETS:

- For iron and steel sheets and plates use United States Standard Gage.
- For sheet copper, brass and german silver, use American (Brown & Sharpe) gage.

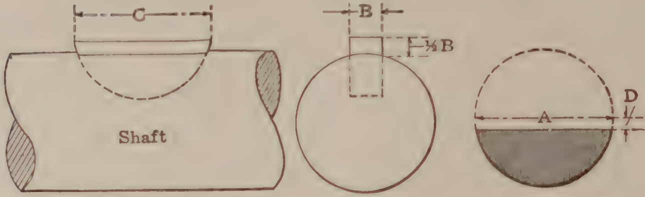
NOTE.—When ordering, it is always well to give the decimal equivalent of the gage size and also the limits plus or minus, that will be acceptable.

Table 7.—Different Standards for Wire Gauges and Sheet-metal Gauges in Use in the United States

Dimensions of sizes in decimal parts of an inch

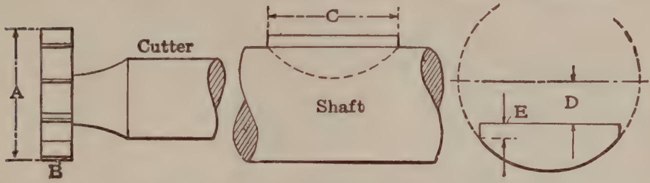
Gage numbers	Steel wire gage	American or Brown & Sharpe gage	American S. & W. Co. *new* music wire gage	Stubs' *steel* wire gage	Birmingham or Stubs' *iron* wire gage	British Imperial Standard wire gage	U. S. Standard gage for sheet and plate iron and steel	Gage numbers
6/0	.4615	.5800	.004	....	....	.464	.4687	6/0
5/0	.4305	.5165	.005	....	.500	.432	.4375	5/0
4/0	.3938	.4600	.006	....	.454	.400	.4062	4/0
3/0	.3625	.4096	.007	....	.425	.372	.375	3/0
2/0	.3310	.3648	.008	....	.380	.348	.3437	2/0
1/0	.3065	.3249	.009	....	.340	.324	.3125	1/0
1	.2830	.2893	.010	.227	.300	.300	.2812	1
2	.2625	.2576	.011	.219	.284	.276	.2656	2
3	.2437	.2294	.012	.212	.259	.252	.25	3
4	.2253	.2043	.013	.207	.238	.232	.2344	4
5	.2070	.1819	.014	.204	.220	.212	.2187	5
6	.1920	.1620	.016	.201	.203	.192	.2031	6
7	.1770	.1442	.018	.199	.180	.176	.1875	7
8	.1620	.1285	.020	.197	.165	.160	.1719	8
9	.1483	.1144	.022	.194	.148	.144	.1562	9
10	.1350	.1019	.024	.191	.134	.128	.1406	10
11	.1205	.0907	.026	.188	.120	.116	.125	11
12	.1055	.0808	.029	.185	.109	.104	.1094	12
13	.0915	.0720	.031	.182	.095	.092	.0937	13
14	.0800	.0641	.033	.180	.083	.080	.0781	14
15	.0720	.0571	.035	.178	.072	.072	.0703	15
16	.0625	.0508	.037	.175	.065	.064	.0625	16
17	.0540	.0452	.039	.172	.058	.056	.05625	17
18	.0475	.0403	.041	.168	.049	.048	.05	18
19	.0410	.0359	.043	.164	.042	.040	.04375	19
20	.0348	.032	.045	.161	.035	.036	.0375	20
21	.0317	.0285	.047	.157	.032	.032	.03437	21
22	.0286	.0253	.049	.155	.028	.028	.03125	22
23	.0258	.0226	.051	.153	.025	.024	.02812	23
24	.0230	.0201	.055	.151	.022	.022	.025	24
25	.0204	.0179	.059	.148	.020	.020	.02187	25
26	.0181	.0159	.063	.146	.018	.018	.01875	26
27	.0173	.0142	.067	.143	.016	.0164	.01718	27
28	.0162	.0126	.071	.139	.014	.0149	.01562	28
29	.0150	.0113	.075	.134	.013	.0136	.01406	29
30	.0140	.01	.080	.127	.012	.0124	.0125	30
31	.0132	.0089	.085	.120	.010	.0116	.01093	31
32	.0128	.00795	.090	.115	.009	.0108	.01015	32
33	.0118	.00708	.095	.112	.008	.0100	.00937	33
34	.0104	.0063	.100	.110	.007	.0092	.00859	34
35	.0095	.0056	.106	.108	.005	.0084	.00781	35
36	.0090	.005	.112	.106	.004	.0076	.00703	36
37	.0085	.00445	.118	.103	....	.0068	.00664	37
38	.0080	.00396	.124	.101	....	.0060	.00625	38
39	.0075	.00353	.130	.099	....	.0052	......	39
40	.0070	.00314	.138	.097	....	.0048	......	40
41	.0066	.00280	....	.095	....	.0044	......	41
42	.0062	.00249	....	.092	....	.0040	......	42
43	.0060	.00222	....	.088	....	.0036	......	43
44	.0058	.00198	....	.085	....	.0032	......	44
45	.0055	.00176	....	.081	....	.0028	......	45
46	.0052	.00157	....	.079	....	.0024	......	46
47	.0050	.00140	....	.077	....	.0020	......	47
48	.0048	.00124	....	.075	....	.0016	......	48
49	.0046	.000986	....	.072	....	.0012	......	49
50	.0044	.000878	....	.069	....	.001	......	50

TABLE 8.—WHITNEY KEYS AND CUTTERS



No. of Key and Cutter	Dia. of Cutter	Thickness of Key and Cutter	Length of Key	Key Cut Below Center	No. of Key and Cutter	Dia. of Cutter	Thickness of Key and Cutter	Length of Key	Key Cut Below Center
	A	B	C	D		A	B	C	D
1	$\frac{1}{2}$	$\frac{1}{16}$	$\frac{1}{2}$	$\frac{3}{64}$	16	$1\frac{1}{8}$	$\frac{3}{16}$	$1\frac{1}{8}$	$\frac{5}{64}$
2	$\frac{1}{2}$	$\frac{3}{32}$	$\frac{1}{2}$	$\frac{3}{64}$	17	$1\frac{1}{8}$	$\frac{7}{32}$	$1\frac{1}{8}$	$\frac{5}{64}$
3	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{1}{2}$	$\frac{3}{64}$	18	$1\frac{1}{8}$	$\frac{1}{4}$	$1\frac{1}{8}$	$\frac{5}{64}$
4	$\frac{5}{8}$	$\frac{3}{32}$	$\frac{5}{8}$	$\frac{1}{16}$	C	$1\frac{1}{8}$	$\frac{5}{16}$	$1\frac{1}{8}$	$\frac{5}{64}$
5	$\frac{5}{8}$	$\frac{1}{8}$	$\frac{5}{8}$	$\frac{1}{16}$	19	$1\frac{1}{4}$	$\frac{3}{16}$	$1\frac{1}{4}$	$\frac{5}{64}$
6	$\frac{5}{8}$	$\frac{5}{32}$	$\frac{5}{8}$	$\frac{1}{16}$	20	$1\frac{1}{4}$	$\frac{7}{32}$	$1\frac{1}{4}$	$\frac{5}{64}$
7	$\frac{3}{4}$	$\frac{1}{8}$	$\frac{3}{4}$	$\frac{1}{16}$	21	$1\frac{1}{4}$	$\frac{1}{4}$	$1\frac{1}{4}$	$\frac{5}{64}$
8	$\frac{3}{4}$	$\frac{5}{32}$	$\frac{3}{4}$	$\frac{1}{16}$	D	$1\frac{1}{4}$	$\frac{5}{16}$	$1\frac{1}{4}$	$\frac{5}{64}$
9	$\frac{3}{4}$	$\frac{3}{16}$	$\frac{3}{4}$	$\frac{1}{16}$	E	$1\frac{1}{4}$	$\frac{3}{8}$	$1\frac{1}{4}$	$\frac{5}{64}$
10	$\frac{7}{8}$	$\frac{5}{32}$	$\frac{7}{8}$	$\frac{1}{16}$	22	$1\frac{3}{8}$	$\frac{1}{4}$	$1\frac{3}{8}$	$\frac{3}{32}$
11	$\frac{7}{8}$	$\frac{3}{16}$	$\frac{7}{8}$	$\frac{1}{16}$	23	$1\frac{3}{8}$	$\frac{5}{16}$	$1\frac{3}{8}$	$\frac{3}{32}$
12	$\frac{7}{8}$	$\frac{7}{32}$	$\frac{7}{8}$	$\frac{1}{16}$	F	$1\frac{3}{8}$	$\frac{3}{8}$	$1\frac{3}{8}$	$\frac{3}{32}$
A	$\frac{7}{8}$	$\frac{1}{4}$	$\frac{7}{8}$	$\frac{1}{16}$	24	$1\frac{1}{2}$	$\frac{1}{4}$	$1\frac{1}{2}$	$\frac{7}{64}$
13	1	$\frac{3}{16}$	1	$\frac{1}{16}$	25	$1\frac{1}{2}$	$\frac{5}{16}$	$1\frac{1}{2}$	$\frac{7}{64}$
14	1	$\frac{7}{32}$	1	$\frac{1}{16}$	G	$1\frac{1}{2}$	$\frac{3}{8}$	$1\frac{1}{2}$	$\frac{7}{64}$
15	1	$\frac{1}{4}$	1	$\frac{1}{16}$					
B	1	$\frac{5}{16}$	1	$\frac{1}{16}$					

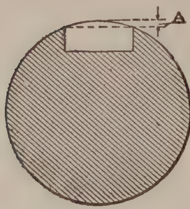
TABLE 8.—WHITNEY KEYS AND CUTTERS.—(*Continued*)



No. of Key and Cutter	Dia. of Cutter	Thickness of Key and Cutter	Length of Key	Key Cut Below Center	Flat at End of Key	No. of Key and Cutter	Dia. of Cutter	Thickness of Key and Cutter	Length of Key	Key Cut Below Center	Flat at End of Key
	A	B	C	D	E		A	B	C	D	E
26	$2\frac{1}{8}$	$\frac{3}{16}$	$1\frac{23}{32}$	$\frac{17}{32}$	$\frac{3}{32}$	30	$3\frac{1}{2}$	$\frac{3}{8}$	$2\frac{7}{8}$	$\frac{13}{16}$	$\frac{3}{16}$
27	$2\frac{1}{8}$	$\frac{1}{4}$	$1\frac{23}{32}$	$\frac{17}{32}$	$\frac{3}{32}$	31	$3\frac{1}{2}$	$\frac{7}{16}$	$2\frac{7}{8}$	$\frac{13}{16}$	$\frac{3}{16}$
28	$2\frac{1}{8}$	$\frac{5}{16}$	$1\frac{23}{32}$	$\frac{17}{32}$	$\frac{3}{32}$	32	$3\frac{1}{2}$	$\frac{1}{2}$	$2\frac{7}{8}$	$\frac{13}{16}$	$\frac{3}{16}$
29	$2\frac{1}{8}$	$\frac{3}{8}$	$1\frac{23}{32}$	$\frac{17}{32}$	$\frac{3}{32}$	33	$3\frac{1}{2}$	$\frac{9}{16}$	$2\frac{7}{8}$	$\frac{13}{16}$	$\frac{3}{16}$
R	$2\frac{3}{4}$	$\frac{1}{4}$	$2\frac{5}{16}$	$\frac{5}{8}$	$\frac{1}{8}$	34	$3\frac{1}{2}$	$\frac{5}{8}$	$2\frac{7}{8}$	$\frac{13}{16}$	$\frac{3}{16}$
S	$2\frac{3}{4}$	$\frac{5}{16}$	$2\frac{5}{16}$	$\frac{5}{8}$	$\frac{1}{8}$	35	$3\frac{1}{2}$	$\frac{11}{16}$	$2\frac{7}{8}$	$\frac{13}{16}$	$\frac{3}{16}$
T	$2\frac{3}{4}$	$\frac{3}{8}$	$2\frac{5}{16}$	$\frac{5}{8}$	$\frac{1}{8}$	36	$3\frac{1}{2}$	$\frac{3}{4}$	$2\frac{7}{8}$	$\frac{13}{16}$	$\frac{3}{16}$
U	$2\frac{3}{4}$	$\frac{7}{16}$	$2\frac{5}{16}$	$\frac{5}{8}$	$\frac{1}{8}$						
V	$2\frac{3}{4}$	$\frac{1}{2}$	$2\frac{5}{16}$	$\frac{5}{8}$	$\frac{1}{8}$						

NOTE.—New numbers have been proposed by the American Standards Association. Numbers in the hundreds place indicate diameter increments in eighths of an inch, and numbers in the tens place indicate width increments in thirty-seconds of an inch. Illustration: 402 indicates a key $\frac{4}{8}$ in. diameter $\times$ $\frac{2}{32}$ wide, or $\frac{1}{2}D \times \frac{1}{16}W$; 1012 indicates $\frac{10}{8}D \times \frac{12}{32}W$ or $1\frac{1}{4}D \times \frac{3}{8}W$.

TABLE 9.—FINDING TOTAL KEYWAY DEPTH



In the column marked "Size of Shaft" find the number representing the size; then to the right find the column representing the keyway to be cut and the decimal there is the distance A, which added to the depth of the keyway will give the total depth from the point where the cutter first begins to cut.

Size of Shaft	1/4 Keyway	5/16 Keyway	3/8 Keyway	7/16 Keyway	1/2 Keyway
1/2	0.0325	....	....	....	....
9/16	0.0289	....	....	....	....
5/8	0.0254	0.0413	....	....	....
11/16	0.0236	0.0379	....	....	....
3/4	0.022	0.0346	0.0511	....	....
13/16	0.0198	0.0314	0.0465	....	....
7/8	0.0177	0.0283	0.042	0.0583	....
15/16	0.0164	0.0264	0.0392	0.0544	....
1	0.0152	0.0246	0.0365	0.0506	0.067
1 1/16	0.0143	0.0228	0.0342	0.0476	0.0625
1 1/8	0.0136	0.021	0.0319	0.0446	0.0581
1 3/16	0.0131	0.0204	0.0304	0.0421	0.0551
1 1/4	0.0127	0.0198	0.029	0.0397	0.0522
1 5/16	0.0123	0.0191	0.0279	0.038	0.0499
1 3/8	0.012	0.0185	0.0268	0.0364	0.0477
1 7/16	0.0114	0.0174	0.0254	0.0346	0.0453
1 1/2	0.011	0.0164	0.024	0.0328	0.0429
1 9/16	0.0107	0.0158	0.0231	0.0309	0.0412
1 5/8	0.0105	0.0153	0.0221	0.0291	0.0395
1 11/16	0.0102	0.0147	0.0214	0.0282	0.0383
1 3/4	0.0099	0.0142	0.0207	0.0274	0.0371
1 13/16	0.0095	0.0136	0.0198	0.0265	0.0355
1 7/8	0.0093	0.013	0.019	0.0257	0.0339
1 15/16	0.009	0.0127	0.0184	0.025	0.0328
2	0.0088	0.0124	0.0179	0.0243	0.0317
2 1/16	0.0083	0.0117	0.0173	0.0236	0.0308
2 1/8	0.0078	0.0111	0.0168	0.0229	0.0299
2 3/16	0.0073	0.0109	0.0163	0.0222	0.0291
2 1/4	0.007	0.0107	0.0159	0.0216	0.0282

For larger sizes see American Machinists' Hand Book.

TABLE 10.—INDEX TABLE FOR FLUTING REAMERS WITH UNEQUAL SPACING

Number of flutes	Index circle	Regular indexing	1st index[1]	2d index	3d index	4th index	5th index	6th index	7th index	8th index
6	39	6 turns + 26 holes	Regular	Reg. + 15 holes	Reg. − 15 holes	See foot	note.[2]			
8	39	5 turns	Regular	Reg. + 15 holes	Reg. − 10 holes	Reg. − 5 holes	See	Fig. 224,	p. 262	
10	39	4 turns	Regular	Reg. − 5 holes	Reg. + 10 holes	Reg. + 5 holes	Reg. − 10 holes			
12	39	3 turns + 13 holes	Regular	Reg. − 7 holes	Reg. + 2 holes	Reg. − 10 holes	Reg. + 6 holes	Reg. + 9 holes		
14	49	2 turns + 42 holes	Regular	Reg. − 7 holes	Reg. + 4 holes	Reg. − 9 holes	Reg. + 6 holes	Reg. + 10 holes	Reg. − 4 holes	
16	20	2 turns + 10 holes	Regular	Reg. − 4 holes	Reg. + 2 holes	Reg. − 3 holes	Reg. + 4 holes	Reg. + 2 holes	Reg. − 4 holes	Reg. + 3 holes

[1] One groove to be cut before 1st indexing operation.

[2] Remaining half of number of grooves on all reamers will be cut like first half, beginning "1st index."

Courtesy Brown & Sharpe Mfg. Co.

Table 11.—Abrasive-wheel Grades

This table gives the grades for vitrified and silicate wheels substantially as listed by the manufacturers named:

Abrasive—American—Bay State—Chicago—Cortland—Desanno—Detroitstar—General—Hampden—Macklin—Norton—Peninsular—Pittsburgh—Presision—Sterling—Vitrified—Waltham—Westfield.

Very soft	Soft	Medium	Hard	Very hard
G-H-I	*J-K-L*	*M-N-O-P*	*Q-R-S*	*T-U*

Elastic wheels are usually graded ½-1-1½-2, etc., to 7. Grade ½, softest; 3, medium; and 7, hardest.

Resinoid wheels are variously classified. For any kind of wheel it is best to have the table of the manufacturer whose wheels are being considered.

Note that the *Carborundum Company* reverses the usual order.

Carborundum Grade Scale

Bond of Wheel	Very hard	Hard	Medium	Soft	Very soft
Vitrified and Silicate.....	D-E	F-G-H	I to M	N to T	U-V-W
Shellac................	......	1-2	3-4-5	6-7-8-9	10
Resinoid...............	......	3-4-5	6-7-8-9-10	11 to 16	17

Table 12.—Gear Wheels

Table of Tooth Parts—Diametral Pitch in First Column

Diametral Pitch	Circular Pitch	Thickness of Tooth on Pitch Line	Addendum	Working Depth of Tooth	Depth of Space below Pitch Line	Whole Depth of Tooth
2	1.5708	.7854	.5000	1.0000	.5785	1.0785
2¼	1.3963	.6981	.4444	.8888	.5143	.9587
2½	1.2566	.6283	.4000	.8000	.4628	.8628
2¾	1.1424	.5712	.3636	.7273	.4208	.7844
3	1.0472	.5236	.3333	.6666	.3857	.7190
3½	.8976	.4488	.2857	.5714	.3306	.6163
4	.7854	.3927	.2500	.5000	.2893	.5393
5	.6283	.3142	.2000	.4000	.2314	.4314
6	.5236	.2618	.1666	.3333	.1928	.3595
7	.4488	.2244	.1429	.2857	.1653	.3081
8	.3927	.1963	.1250	.2500	.1446	.2696
9	.3491	.1745	.1111	.2222	.1286	.2397
10	.3142	.1571	.1000	.2000	.1157	.2157
11	.2856	.1428	.0909	.1818	.1052	.1961
12	.2618	.1309	.0833	.1666	.0964	.1798
13	.2417	.1208	.0769	.1538	.0890	.1659
14	.2244	.1122	.0714	.1429	.0826	.1541
15	.2094	.1047	.0666	.1333	.0771	.1438
16	.1963	.0982	.0625	.1250	.0723	.1348
17	.1848	.0924	.0588	.1176	.0681	.1269
18	.1745	.0873	.0555	.1111	.0643	.1198
19	.1653	.0827	.0526	.1053	.0609	.1135
20	.1571	.0785	.0500	.1000	.0579	.1079
22	.1428	.0714	.0455	.0909	.0526	.0980
24	.1309	.0654	.0417	.0833	.0482	.0898
26	.1208	.0604	.0385	.0769	.0445	.0829
28	.1122	.0561	.0357	.0714	.0413	.0770
30	.1047	.0524	.0333	.0666	.0386	.0719

To obtain the size of any part of a diametral pitch not given in the table, divide the corresponding part of 1 diametral pitch by the pitch required.

TABLE 13.—THE DIMENSIONS OF GEARS BY METRIC PITCH

Module is the pitch diameter in millimeters divided by the number of teeth in the gear.

Pitch diameter in millimeters is the module multiplied by the number of teeth in the gear.

M = Module.
PD = The pitch diameter of gear.
OD = The outside diameter of gear.
N = The number of teeth in gear.
WD = The whole depth of teeth.
CTh = Thickness of teeth on pitch line.
C = Amount added to depth for clearance.

Then

$$A = M$$

$$M = \frac{PD}{N} \text{ or } \frac{OD}{N+2}.$$

$$PD = NM.$$

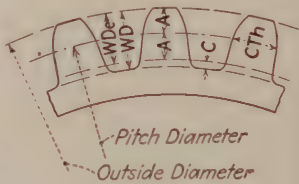
$$OD = (N + 2)M.$$

$$N = \frac{PD}{M} \text{ or } \frac{OD}{M} - 2.$$

$$W\,De = 2M.$$

$$CTh = M \times 1.5708.$$

$$C = \frac{M \times 1.5708}{10} = 0.157M.$$



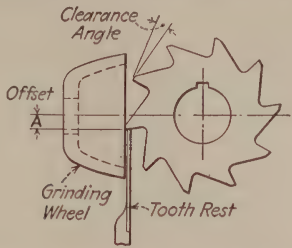
The module is equal to the part marked A in cut, measured in millimeters and parts of millimeter.

Example.—Module = 3.50 mm., 100 teeth.
Pitch diameter = 3.5 × 100 = 350 mm.
Outside diameter = (100 + 2) × 3.5 = 357 mm.

PITCHES COMMONLY USED—MODULE IN MILLIMETERS

Module	Corresponding English Diametral Pitch	Module	Corresponding English Diametral Pitch
½ mm.	50.800	4.5 mm.	5.644
¾	33.867	5	5.080
1	25.400	5.5	4.618
1.25	20.320	6	4.233
1.5	16.933	7	3.628
1.75	14.514	8	3.175
2	12.700	9	2.822
2.25	11.288	10	2.540
2.5	10.160	11	2.309
2.75	9.236	12	2.117
3	8.466	14	1.814
3.5	7.257	16	1.587
4	6.350		

TABLE 14.—OFFSETS FOR OBTAINING CLEARANCE ON MILLING CUTTERS



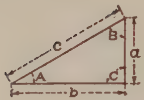
Have the tooth rest the distance *A* below the center line of the cutter according to the amount shown in the table for the diameter of the given cutter and the clearance angle desired.

Example.—For a cutter of 5-in. dia., 4-deg. clearance, offset *A* is 0.174 in

Dia. of cutter	Clearance angles and offsets					Dia. of cutter	Clearance angles and offsets			
	3°	4°	6°	8°	10°		3°	4°	6°	8°
1/8	0.003	0.004	0.006	0.009	0.011	3 3/4	0.098	0.131	0.170	0.261
1/4	0.006	0.009	0.013	0.017	0.022	4	0.104	0.139	0.209	0.278
3/8	0.010	0.013	0.019	0.026	0.032	4 1/2	0.118	0.157	0.235	0.313
1/2	0.013	0.017	0.026	0.035	0.043	5	0.131	0.174	0.261	0.348
5/8	0.016	0.022	0.033	0.043	0.054	5 1/2	0.144	0.192	0.287	0.383
3/4	0.020	0.026	0.039	0.052	0.065	6	0.157	0.209	0.313	0.417
7/8	0.023	0.030	0.046	0.061	0.076	6 1/2	0.170	0.227	0.340	0.452
1	0.026	0.035	0.052	0.069	0.087	7	0.183	0.244	0.366	0.487
1 1/4	0.033	0.044	0.065	0.087		7 1/2	0.196	0.262	0.392	0.522
1 1/2	0.039	0.052	0.078	0.104		8	0.209	0.279	0.418	0.557
1 3/4	0.046	0.061	0.091	0.122		8 1/2	0.222	0.296	0.444	0.591
2	0.052	0.070	0.104	0.139		9	0.235	0.314	0.470	0.626
2 1/4	0.059	0.078	0.117	0.156		9 1/2	0.249	0.331	0.496	0.661
2 1/2	0.065	0.087	0.131	0.174		10	0.262	0.349	0.523	0.696
2 3/4	0.072	0.096	0.144	0.191		11	0.288	0.384	0.575	0.765
3	0.078	0.105	0.157	0.209		12	0.314	0.418	0.627	0.835
3 1/4	0.085	0.113	0.170	0.226		13	0.340	0.453	0.679	0.905
3 1/2	0.091	0.122	0.183	0.243		14	0.366	0.488	0.732	0.974

TABLE 15.—TRIGONOMETRICAL FORMULAS, ETC.

Geometrical Solution of Right-angled Triangles

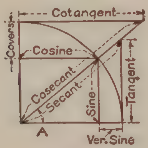


$$c = \sqrt{a^2 + b^2}$$
$$b = \sqrt{c^2 - a^2}$$
$$a = \sqrt{c^2 - b^2}$$

$$\sin A = \frac{a}{c} = \frac{\text{opposite side}}{\text{hypotenuse}} \qquad \cos A = \frac{b}{c} = \frac{\text{adjacent side}}{\text{hypotenuse}}$$

$$\tan A = \frac{a}{b} = \frac{\text{opposite side}}{\text{adjacent side}} \qquad \cot A = \frac{b}{a} = \frac{\text{adjacent side}}{\text{opposite side}}$$

$$\sec A = \frac{c}{b} = \frac{\text{hypotenuse}}{\text{adjacent side}} \qquad \text{cosec } A = \frac{c}{a} = \frac{\text{hypotenuse}}{\text{opposite side}}$$



General Equivalents

The illustration shows the different trigonometrical expressions in terms of the angle A.

In the following formulas the radius = 1.

Complement of an angle = its difference from 90 deg.
Supplement of an angle = its difference from 180 deg.

$$\sin = \frac{1}{\text{cosec}} = \frac{\cos}{\cot} = \sqrt{(1 - \cos^2)}$$

$$\cos = \sqrt{(1 - \sin^2)} = \frac{\sin}{\tan} = \sin \times \cot = \frac{1}{\sec}$$

$$\sec = \sqrt{\text{rad}^2 + \tan^2} = \frac{1}{\cos} = \frac{\tan}{\sin} \qquad \text{cosec} = \frac{1}{\sin}$$

$$\tan = \frac{\sin}{\cos} = \frac{1}{\cot} \qquad \cot = \frac{\cos}{\sin} = \frac{1}{\tan}$$

$$\text{versin} = \text{rad} - \cos \qquad \text{coversin} = \text{rad} - \sin$$

$$\text{rad} = \tan \times \cot = \sqrt{\sin^2 + \cos^2}$$

TABLE 16.—TRIGONOMETRIC FUNCTIONS

Angles	Sines		Cosines		Tangents		Cotangents		Angles
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
0° 00′	.0000	∞	1.0000	0.0000	.0000	∞	∞	∞	90° 00′
10	.0029	7.4637	1.0000	0000	.0029	7.4637	343.77	2.5363	50
20	.0058	7648	1.0000	0000	.0058	7648	171.89	2352	40
30	.0087	9408	1.0000	0000	.0087	9409	114.59	0591	30
40	.0116	8.0658	.9999	0000	.0116	8.0658	85.940	1.9342	20
50	.0145	1627	.9999	0000	.0145	1627	68.750	8373	10
1° 00′	.0175	8.2419	.9998	9.9999	.0175	8.2419	57.290	1.7581	89° 00′
10	.0204	3088	.9998	9999	.0204	3089	49.104	6911	50
20	.0233	3668	.9997	9999	.0233	3669	42.964	6331	40
30	.0262	4179	.9997	9999	.0262	4181	38.188	5819	30
40	.0291	4637	.9996	9998	.0291	4638	34.368	5362	20
50	.0320	5050	.9995	9998	.0320	5053	31.242	4947	10
2° 00′	.0349	8.5428	.9994	9.9997	.0349	8.5431	28.636	1.4569	88° 00′
10	.0378	5776	.9993	9997	.0378	5779	26.432	4221	50
20	.0407	6097	.9992	9996	.0407	6101	24.542	3899	40
30	.0436	6397	.9990	9996	.0437	6401	22.904	3599	30
40	.0465	6677	.9989	9995	.0466	6682	21.470	3318	20
50	.0494	6940	.9988	9995	.0495	6945	20.206	3055	10
3° 00′	.0523	8.7188	.9986	9.9994	.0524	8.7194	19.081	1.2806	87° 00′
10	.0552	7423	.9985	9993	.0553	7429	18.075	2571	50
20	.0581	7645	.9983	9993	.0582	7652	17.169	2348	40
30	.0610	7857	.9981	9992	.0612	7865	16.350	2135	30
40	.0640	8059	.9980	9991	.0641	8067	15.605	1933	20
50	.0669	8251	.9978	9990	.0670	8261	14.924	1739	10
4° 00′	.0698	8.8436	.9976	9.9989	.0699	8.8446	14.301	1.1554	86° 00′
10	.0727	8613	.9974	9989	.0729	8624	13.727	1376	50
20	.0756	8783	.9971	9988	.0758	8795	13.197	1205	40
30	.0785	8946	.9969	9987	.0787	8960	12.706	1040	30
40	.0814	9104	.9967	9986	.0816	9118	12.251	0882	20
50	.0843	9256	.9964	9985	.0846	9272	11.826	0728	10
5° 00′	.0872	8.9403	.9962	9.9983	.0875	8.9420	11.430	1.0580	85° 00′
10	.0901	9545	.9959	9982	.0904	9563	11.059	0437	50
20	.0929	9682	.9957	9981	.0934	9701	10.712	0299	40
30	.0958	9816	.9954	9980	.0963	9836	10.385	0164	30
40	.0987	9945	.9951	9979	.0992	9966	10.078	0034	20
50	.1016	9.0070	.9948	9977	.1022	9.0093	9.7882	0.9907	10
6° 00′	.1045	9.0192	.9945	9.9976	.1051	9.0216	9.5144	0.9784	84° 00′
10	.1074	0311	.9942	9975	.1080	0336	9.2553	9664	50
20	.1103	0426	.9939	9973	.1110	0453	9.0098	9547	40
30	.1132	0539	.9936	9972	.1139	0567	8.7769	9433	30
40	.1161	0648	.9932	9971	.1169	0678	8.5555	9322	20
50	.1190	0755	.9929	9969	.1198	0786	8.3450	9214	10
7° 00′	.1219	9.0859	.9925	9.9968	.1228	9.0891	8.1443	0.9109	83° 00′
10	.1248	0961	.9922	9966	.1257	0995	7.9530	9005	50
20	.1276	1060	.9918	9964	.1287	1096	7.7704	8904	40
30	.1305	1157	.9914	9963	.1317	1194	7.5958	8806	30
40	.1334	1252	.9911	9961	.1346	1291	7.4287	8709	20
50	.1363	1345	.9907	9959	.1376	1385	7.2687	8615	10
8° 00′	.1392	9.1436	.9903	9.9958	.1405	9.1478	7.1154	0.8522	82° 00′
10	.1421	1525	.9899	9956	.1435	1569	6.9682	8431	50
20	.1449	1612	.9894	9954	.1465	1658	6.8269	8342	40
30	.1478	1697	.9890	9952	.1495	1745	6.6912	8255	30
40	.1507	1781	.9886	9950	.1524	1831	6.5606	8169	20
50	.1536	1863	.9881	9948	.1554	1915	6.4348	8085	10
9° 00′	.1564	9.1943	.9877	9.9946	.1584	9.1997	6.3138	0.8003	81° 00′
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
Angles	Cosines		Sines		Cotangents		Tangents		Angles

TABLE 16.—TRIGONOMETRIC FUNCTIONS.—(*Continued*)

Angles	Sines		Cosines		Tangents		Cotangents		Angles
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
9° 00′	.1564	9.1943	.9877	9.9946	.1584	9.1997	6.3138	0.8003	81° 00′
10	.1593	2022	.9872	9944	.1614	2078	6.1970	7922	50
20	.1622	2100	.9868	9942	.1644	2158	6.0844	7842	40
30	.1650	2176	.9863	9940	.1673	2236	5.9758	7764	30
40	.1679	2251	.9858	9938	.1703	2313	5.8708	7687	20
50	.1708	2324	.9853	9936	.1733	2389	5.7694	7611	10
10° 00′	.1736	9.2397	.9848	9.9934	.1763	9.2463	5.6713	0.7537	80° 00′
10	.1765	2468	.9843	9931	.1793	2536	5.5764	7464	50
20	.1794	2538	.9838	9929	.1823	2609	5.4845	7391	40
30	.1822	2606	.9833	9927	.1853	2680	5.3955	7320	30
40	.1851	2674	.9827	9924	.1883	2750	5.3093	7250	20
50	.1880	2740	.9822	9922	.1914	2819	5.2257	7181	10
11° 00′	.1908	9.2806	.9816	9.9919	.1944	9.2887	5.1446	0.7113	79° 00′
10	.1937	2870	.9811	9917	.1974	2953	5.0658	7047	50
20	.1965	2934	.9805	9914	.2004	3020	4.9894	6980	40
30	.1994	2997	.9799	9912	.2035	3085	4.9152	6915	30
40	.2022	3058	.9793	9909	.2065	3149	4.8430	6851	20
50	.2051	3119	.9787	9907	.2095	3212	4.7729	6788	10
12° 00′	.2079	9.3179	.9781	9.9904	.2126	9.3275	4.7046	0.6725	78° 00′
10	.2108	3238	.9775	9901	.2156	3336	4.6382	6664	50
20	.2136	3296	.9769	9899	.2186	3397	4.5736	6603	40
30	.2164	3353	.9763	9896	.2217	3458	4.5107	6542	30
40	.2193	3410	.9757	9893	.2247	3517	4.4494	6483	20
50	.2221	3466	.9750	9890	.2278	3576	4.3897	6424	10
13° 00′	.2250	9.3521	.9744	9.9887	.2309	9.3634	4.3315	0.6366	77° 00′
10	.2278	3575	.9737	9884	.2339	3691	4.2747	6309	50
20	.2306	3629	.9730	9881	.2370	3748	4.2193	6252	40
30	.2334	3682	.9724	9878	.2401	3804	4.1653	6196	30
40	.2363	3734	.9717	9875	.2432	3859	4.1126	6141	20
50	.2391	3786	.9710	9872	.2462	3914	4.0611	6086	10
14° 00′	.2419	9.3837	.9703	9.9869	.2493	9.3968	4.0108	0.6032	76° 00′
10	.2447	3887	.9696	9866	.2524	4021	3.9617	5979	50
20	.2476	3937	.9689	9863	.2555	4074	3.9136	5926	40
30	.2504	3986	.9681	9859	.2586	4127	3.8667	5873	30
40	.2532	4035	.9674	9856	.2617	4178	3.8208	5822	20
50	.2560	4083	.9667	9853	.2648	4230	3.7760	5770	10
15° 00′	.2588	9.4130	.9659	9.9849	.2679	9.4281	3.7321	0.5719	75° 00′
10	.2616	4177	.9652	9846	.2711	4331	3.6891	5669	50
20	.2644	4223	.9644	9843	.2742	4381	3.6470	5619	40
30	.2672	4269	.9636	9839	.2773	4430	3.6059	5570	30
40	.2700	4314	.9628	9836	.2805	4479	3.5656	5521	20
50	.2728	4359	.9621	9832	.2836	4527	3.5261	5473	10
16° 00′	.2756	9.4403	.9613	9.9828	.2867	9.4575	3.4874	0.5425	74° 00′
10	.2784	4447	.9605	9825	.2899	4622	3.4495	5378	50
20	.2812	4491	.9596	9821	.2931	4669	3.4124	5331	40
30	.2840	4533	.9588	9817	.2962	4716	3.3759	5284	30
40	.2868	4576	.9580	9814	.2994	4762	3.3402	5238	20
50	.2896	4618	.9572	9810	.3026	4808	3.3052	5192	10
17° 00′	.2924	9.4659	.9563	9.9806	.3057	9.4853	3.2709	0.5147	73° 00′
10	.2952	4700	.9555	9802	.3089	4898	3.2371	5102	50
20	.2979	4741	.9546	9798	.3121	4943	3.2041	5057	40
30	.3007	4781	.9537	9794	.3153	4987	3.1716	5013	30
40	.3035	4821	.9528	9790	.3185	5031	3.1397	4969	20
50	.3062	4861	.9520	9786	.3217	5075	3.1084	4925	10
18° 00′	.3090	9.4900	.9511	9.9782	.3249	9.5118	3.0777	0.4882	72° 00′
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
Angles	Cosines		Sines		Cotangents		Tangents		Angles

TABLE 16.—TRIGONOMETRIC FUNCTIONS.—(*Continued*)

Angles	Sines		Cosines		Tangents		Cotangents		Angles
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
18° 00′	.3090	9.4900	.9511	9.9782	.3249	9.5118	3.0777	0.4882	72° 00′
10	.3118	4939	.9502	9778	.3281	5161	3.0475	4839	50
20	.3145	4977	.9492	9774	.3314	5203	3.0178	4797	40
30	.3173	5015	.9483	9770	.3346	5245	2.9887	4755	30
40	.3201	5052	.9474	9765	.3378	5287	2.9600	4713	20
50	.3228	5090	.9465	9761	.3411	5329	2.9319	4671	10
19° 00′	.3256	9.5126	.9455	9.9757	.3443	9.5370	2.9042	0.4630	71° 00′
10	.3283	5163	.9446	9752	.3476	5411	2.8770	4589	50
20	.3311	5199	.9436	9748	.3508	5451	2.8502	4549	40
30	.3338	5235	.9426	9743	.3541	5491	2.8239	4509	30
40	.3365	5270	.9417	9739	.3574	5531	2.7980	4469	20
50	.3393	5306	.9407	9734	.3607	5571	2.7725	4429	10
20° 00′	.3420	9.5341	.9397	9.9730	.3640	9.5611	2.7475	0.4389	70° 00′
10	.3448	5375	.9387	9725	.3673	5650	2.7228	4350	50
20	.3475	5409	.9377	9721	.3706	5689	2.6985	4311	40
30	.3502	5443	.9367	9716	.3739	5727	2.6746	4273	30
40	.3529	5477	.9356	9711	.3772	5766	2.6511	4234	20
50	.3557	5510	.9346	9706	.3805	5804	2.6279	4196	10
21° 00′	.3584	9.5543	.9336	9.9702	.3839	9.5842	2.6051	0.4158	69° 00′
10	.3611	5576	.9325	9697	.3872	5879	2.5826	4121	50
20	.3638	5609	.9315	9692	.3906	5917	2.5605	4083	40
30	.3665	5641	.9304	9687	.3939	5954	2.5386	4046	30
40	.3692	5673	.9293	9682	.3973	5991	2.5172	4009	20
50	.3719	5704	.9283	9677	.4006	6028	2.4960	3972	10
22° 00′	.3746	9.5736	.9272	9.9672	.4040	9.6064	2.4751	0.3936	68° 00′
10	.3773	5767	.9261	9667	.4074	6100	2.4545	3900	50
20	.3800	5798	.9250	9661	.4108	6136	2.4342	3864	40
30	.3827	5828	.9239	9656	.4142	6172	2.4142	3828	30
40	.3854	5859	.9228	9651	.4176	6208	2.3945	3792	20
50	.3881	5889	.9216	9646	.4210	6243	2.3750	3757	10
23° 00′	.3907	9.5919	.9205	9.9640	.4245	9.6279	2.3559	0.3721	67° 00′
10	.3934	5948	.9194	9635	.4279	6314	2.3369	3686	50
20	.3961	5978	.9182	9629	.4314	6348	2.3183	3652	40
30	.3987	6007	.9171	9624	.4348	6383	2.2998	3617	30
40	.4014	6036	.9159	9618	.4383	6417	2.2817	3583	20
50	.4041	6065	.9147	9613	.4417	6452	2.2637	3548	10
24° 00′	.4067	9.6093	.9135	9.9607	.4452	9.6486	2.2460	0.3514	66° 00′
10	.4094	6121	.9124	9602	.4487	6520	2.2286	3480	50
20	.4120	6149	.9112	9596	.4522	6553	2.2113	3447	40
30	.4147	6177	.9100	9590	.4557	6587	2.1943	3413	30
40	.4173	6205	.9088	9584	.4592	6620	2.1775	3380	20
50	.4200	6232	.9075	9579	.4628	6654	2.1609	3346	10
25° 00′	4226	9.6259	.9063	9.9573	.4663	9.6687	2.1445	0.3313	65° 00′
10	.4253	6286	.9051	9567	.4699	6720	2.1283	3280	50
20	.4279	6313	.9038	9561	.4734	6752	2.1123	3248	40
30	.4305	6340	.9026	9555	.4770	6785	2.0965	3215	30
40	.4331	6366	.9013	9549	.4806	6817	2.0809	3183	20
50	.4358	6392	.9001	9543	.4841	6850	2.0655	3150	10
26° 00′	.4384	9.6418	.8988	9.9537	.4877	9.6882	2.0503	0.3118	64° 00′
10	.4410	6444	.8975	9530	.4913	6914	2.0353	3086	50
20	.4436	6470	.8962	9524	.4950	6946	2.0204	3054	40
30	.4462	6495	.8949	9518	.4986	6977	2.0057	3023	30′
40	.4488	6521	.8936	9512	.5022	7009	1.9912	2991	20
50	.4514	6546	.8923	9505	.5059	7040	1.9768	2960	10
27° 00′	.4540	9.6570	.8910	9.9499	.5095	9.7072	1.9626	0.2928	63° 00′
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
Angles	Cosines		Sines		Cotangents		Tangents		Angles

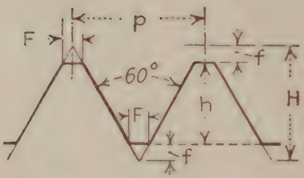
TABLE 16.—TRIGONOMETRIC FUNCTIONS.—(*Continued*)

Angles	Sines		Cosines		Tangents		Cotangents		Angles
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
27° 00′	.4540	9.6570	.8910	9.9499	.5095	9.7072	1.9626	0.2928	63° 00′
10	.4566	6595	.8897	9492	.5132	7103	1.9486	2897	50
20	.4592	6620	.8884	9486	.5169	7134	1.9347	2866	40
30	.4617	6644	.8870	9479	.5206	7165	1.9210	2835	30
40	.4643	6668	.8857	9473	.5243	7196	1.9074	2804	20
50	.4669	6692	.8843	9466	.5280	7226	1.8940	2774	10
28° 00′	.4695	9.6716	.8829	9.9459	.5317	9.7257	1.8807	0.2743	62° 00′
10	.4720	6740	.8816	9453	.5354	7287	1.8676	2713	50
20	.4746	6763	.8802	9446	.5392	7317	1.8546	2683	40
30	.4772	6787	.8788	9439	.5430	7348	1.8418	2652	30
40	.4797	6810	.8774	9432	.5467	7378	1.8291	2622	20
50	.4823	6833	.8760	9425	.5505	7408	1.8165	2592	10
29° 00′	.4848	9.6856	.8746	9.9418	.5543	9.7438	1.8040	0.2562	61° 00′
10	.4874	6878	.8732	9411	.5581	7467	1.7917	2533	50
20	.4899	6901	.8718	9404	.5619	7497	1.7796	2503	40
30	.4924	6923	.8704	9397	.5658	7526	1.7675	2474	30
40	.4950	6946	.8689	9390	.5696	7556	1.7556	2444	20
50	.4975	6968	.8675	9383	.5735	7585	1.7437	2415	10
30° 00′	.5000	9.6990	.8660	9.9375	.5774	9.7614	1.7321	0.2386	60° 00′
10	.5025	7012	.8646	9368	.5812	7644	1.7205	2356	50
20	.5050	7033	.8631	9361	.5851	7673	1.7090	2327	40
30	.5075	7055	.8616	9353	.5890	7701	1.6977	2299	30
40	.5100	7076	.8601	9346	.5930	7730	1.6864	2270	20
50	.5125	7097	.8587	9338	.5969	7759	1.6753	2241	10
31° 00′	.5150	9.7118	.8572	9.9331	.6009	9.7788	1.6643	0.2212	59° 00′
10	.5175	7139	.8557	9323	.6048	7816	1.6534	2184	50
20	.5200	7160	.8542	9315	.6088	7845	1.6426	2155	40
30	.5225	7181	.8526	9308	.6128	7873	1.6319	2127	30
40	.5250	7201	.8511	9300	.6168	7902	1.6212	2098	20
50	.5275	7222	.8496	9292	.6208	7930	1.6107	2070	10
32° 00′	.5299	9.7242	.8480	9.9284	.6249	9.7958	1.6003	0.2042	58° 00′
10	.5324	7262	.8465	9276	.6289	7986	1.5900	2014	50
20	.5348	7282	.8450	9268	.6330	8014	1.5798	1986	40
30	.5373	7302	.8434	9260	.6371	8042	1.5697	1958	30
40	.5398	7322	.8418	9252	.6412	8070	1.5597	1930	20
50	.5422	7342	.8403	9244	.6453	8097	1.5497	1903	10
33° 00′	.5446	9.7361	.8387	9.9236	.6494	9.8125	1.5399	0.1875	57° 00′
10	.5471	7380	.8371	9228	.6536	8153	1.5301	1847	50
20	.5495	7400	.8355	9219	.6577	8180	1.5204	1820	40
30	.5519	7419	.8339	9211	.6619	8208	1.5108	1792	30
40	.5544	7438	.8323	9203	.6661	8235	1.5013	1765	20
50	.5568	7457	.8307	9194	.6703	8263	1.4919	1737	10
34° 00′	.5592	9.7476	.8290	9.9186	.6745	9.8290	1.4826	0.1710	56° 00′
10	.5616	7494	.8274	9177	.6787	8317	1.4733	1683	50
20	.5640	7513	.8258	9169	.6830	8344	1.4641	1656	40
30	.5664	7531	.8241	9160	.6873	8371	1.4550	1629	30
40	.5688	7550	.8225	9151	.6916	8398	1.4460	1602	20
50	.5712	7568	.8208	9142	.6959	8425	1.4370	1575	10
35° 00′	.5736	9.7586	.8192	9.9134	.7002	9.8452	1.4281	0.1548	55° 00′
10	.5760	7604	.8175	9125	.7046	8479	1.4193	1521	50
20	.5783	7622	.8158	9116	.7089	8506	1.4106	1494	40
30	.5807	7640	.8141	9107	.7133	8533	1.4019	1467	30
40	.5831	7657	.8124	9098	.7177	8559	1.3934	1441	20
50	.5854	7675	.8107	9089	.7221	8586	1.3848	1414	10
36° 00′	.5878	9.7692	.8090	9.9080	.7265	9.8613	1.3764	0.1387	54° 00′
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
Angles	Cosines		Sines		Cotangents		Tangents		Angles

TABLE 16.—TRIGONOMETRIC FUNCTIONS.—(*Concluded*)

Angles	Sines		Cosines		Tangents		Cotangents		Angles
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
36° 00′	.5878	9.7692	.8090	9.9080	.7265	9.8613	1.3764	0.1387	54° 00′
10	.5901	7710	.8073	9070	.7310	8639	1.3680	1361	50
20	.5925	7727	.8056	9061	.7355	8666	1.3597	1334	40
30	.5948	7744	.8039	9052	.7400	8692	1.3514	1308	30
40	.5972	7761	.8021	9042	.7445	8718	1.3432	1282	20
50	.5995	7778	.8004	9033	.7490	8745	1.3351	1255	10
37° 00′	.6018	9.7795	.7986	9.9023	.7536	9.8771	1.3270	0.1229	53° 00′
10	.6041	7811	.7969	9014	.7581	8797	1.3190	1203	50
20	.6065	7828	.7951	9004	.7627	8824	1.3111	1176	40
30	.6088	7844	.7934	8995	.7673	8850	1.3032	1150	30
40	.6111	7861	.7916	8985	.7720	8876	1.2954	1124	20
50	.6134	7877	.7898	8975	.7766	8902	1.2876	1098	10
38° 00′	.6157	9.7893	.7880	9.8965	.7813	9.8928	1.2799	0.1072	52° 00′
10	.6180	7910	.7862	8955	.7860	8954	1.2723	1046	50
20	.6202	7926	.7844	8945	.7907	8980	1.2647	1020	40
30	.6225	7941	.7826	8935	.7954	9006	1.2572	0994	30
40	.6248	7957	.7808	8925	.8002	9032	1.2497	0968	20
50	.6271	7973	.7790	8915	.8050	9058	1.2423	0942	10
39° 00′	.6293	9.7989	.7771	9.8905	.8098	9.9084	1.2349	0.0916	51° 00′
10	.6316	8004	.7753	8895	.8146	9110	1.2276	0890	50
20	.6338	8020	.7735	8884	.8195	9135	1.2203	0865	40
30	.6361	8035	.7716	8874	.8243	9161	1.2131	0839	30
40	.6383	8050	.7698	8864	.8292	9187	1.2059	0813	20
50	.6406	8066	.7679	8853	.8342	9212	1.1988	0788	10
40° 00′	.6428	9.8081	.7660	9.8843	.8391	9.9238	1.1918	0.0762	50° 00′
10	.6450	8096	.7642	8832	.8441	9264	1.1847	0736	50
20	.6472	8111	.7623	8821	.8491	9289	1.1778	0711	40
30	.6494	8125	.7604	8810	.8541	9315	1.1708	0685	30
40	.6517	8140	.7585	8800	.8591	9341	1.1640	0659	20
50	.6539	8155	.7566	8789	.8642	9366	1.1571	0634	10
41° 00′	.6561	9.8169	.7547	9.8778	.8693	9.9392	1.1504	0.0608	49° 00′
10	.6583	8184	.7528	8767	.8744	9417	1.1436	0583	50
20	.6604	8198	.7509	8756	.8796	9443	1.1369	0557	40
30	.6626	8213	.7490	8745	.8847	9468	1.1303	0532	30
40	.6648	8227	.7470	8733	.8899	9494	1.1237	0506	20
50	.6670	8241	.7451	8722	.8952	9519	1.1171	0481	10
42° 00′	.6691	9.8255	.7431	9.8711	.9004	9.9544	1.1106	0.0456	48° 00′
10	.6713	8269	.7412	8699	.9057	9570	1.1041	0430	50
20	.6734	8283	.7392	8688	.9110	9595	1.0977	0405	40
30	.6756	8297	.7373	8676	.9163	9621	1.0913	0379	30
40	.6777	8311	.7353	8665	.9217	9646	1.0850	0354	20
50	.6799	8324	.7333	8653	.9271	9671	1.0786	0329	10
43° 00′	.6820	9.8338	.7314	9.8641	.9325	9.9697	1.0724	0.0303	47° 00′
10	.6841	8351	.7294	8629	.9380	9722	1.0661	0278	50
20	.6862	8365	.7274	8618	.9435	9747	1.0599	0253	40
30	.6884	8378	.7254	8606	.9490	9772	1.0538	0228	30
40	.6905	8391	.7234	8594	.9545	9798	1.0477	0202	20
50	.6926	8405	.7214	8582	.9601	9823	1.0416	0177	10
44° 00′	.6947	9.8418	.7193	9.8569	.9657	9.9848	1.0355	0.0152	46° 00′
10	.6967	8431	.7173	8557	.9713	9874	1.0295	0126	50
20	.6988	8444	.7153	8545	.9770	9899	1.0235	0101	40
30	.7009	8457	.7133	8532	.9827	9924	1.0176	0076	30
40	.7030	8469	.7112	8520	.9884	9949	1.0117	0051	20
50	.7050	8482	.7092	8507	.9942	9975	1.0058	0025	10
45° 00′	.7071	9.8495	.7071	9.8495	1.0000	0.0000	1.0000	0.0000	45° 00′
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
Angles	Cosines		Sines		Cotangents		Tangents		Angles

TABLE 17.—AMERICAN STANDARD SCREW THREADS
NATIONAL COARSE (NC) AND NATIONAL FINE (NF)
Thread Dimensions and Tap-drill Sizes



n = no. of threads per inch

$p \text{ (pitch)} = \dfrac{1}{\text{no. of threads per inch}} = \dfrac{1}{n}$

$h \text{ (depth)} = 0.649519p = \dfrac{0.649519}{n}$

H (depth, sharp V thread) $= 0.866025p$

$f = \dfrac{H}{8}$ = depth of basic truncation

$F = 0.125p = \dfrac{p}{8}$ = width of basic flat at top, crest or root

National Coarse is the former U. S. Standard for sizes ¼ in. and larger, while for sizes under ¼ in. it is the coarse threads of the former A. S. M. E. machine-screw sizes.

National Fine is the former S. A. E. Standard for sizes ¼ in. and larger, while for sizes under ¼ in. it is the fine threads of the former A. S. M. E. machine-screw sizes.

* American National Standard wood screws are made in same numbers and corresponding body diameters as starred sizes.

Nominal size and No. threads per inch	Major diameter	Pitch diameter	Minor diameter	Commercial tap drill to produce approx. 75 % full thread	Decimal equivalent of tap drill
*0-80	0.0600	0.0519	0.0438	3-64	0.0469
*1-64	0.0730	0.0629	0.0527	53	0.0595
72	0.0730	0.0640	0.0550	53	0.0595
*2-56	0.0860	0.0744	0.0628	50	0.0700
64	0.0860	0.0759	0.0657	50	0.0700
*3-48	0.0990	0.0855	0.0719	47	0.0785
56	0.0990	0.0874	0.0758	45	0.0820
*4-40	0.1120	0.0958	0.0795	43	0.0890
48	0.1120	0.0985	0.0849	42	0.0935
*5-40	0.1250	0.1088	0.0925	38	0.1015
44	0.1250	0.1102	0.0955	37	0.1040
*6-32	0.1380	0.1177	0.0974	36	0.1065
40	0.1380	0.1218	0.1055	33	0.1130
*8-32	0.1640	0.1437	0.1234	29	0.1360
36	0.1640	0.1460	0.1279	29	0.1360
*10-24	0.1900	0.1629	0.1359	25	0.1495
32	0.1900	0.1697	0.1494	21	0.1590
*12-24	0.2160	0.1889	0.1619	16	0.1770
28	0.2160	0.1928	0.1696	14	0.1820
¼-20	0.2500	0.2175	0.1850	7	0.2010
28	0.2500	0.2268	0.2036	3	0.2130
5⁄16-18	0.3125	0.2764	0.2403	F	0.2570
24	0.3125	0.2854	0.2584	I	0.2720
⅜-16	0.3750	0.3344	0.2938	5-16	0.3125
24	0.3750	0.3479	0.3209	Q	0.3320

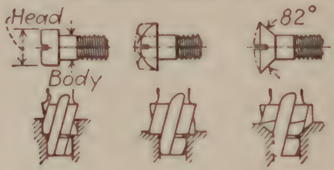
TABLE 17.—AMERICAN STANDARD SCREW THREADS.—(*Continued*)

Nominal size and No. threads per inch	Major diameter	Pitch diameter	Minor diameter	Commercial tap drill to produce approx. 75 % full thread	Decimal equivalent of tap drill
7/16-14	0.4375	0.3911	0.3447	U	0.3680
20	0.4375	0.4050	0.3726	25-64	0.3906
1/2-13	0.5000	0.4501	0.4001	27-64	0.4219
20	0.5000	0.4675	0.4351	29-64	0.4531
9/16-12	0.5625	0.5084	0.4542	31-64	0.4844
18	0.5625	0.5264	0.4903	33-64	0.5156
5/8-11	0.6250	0.5660	0.5069	17-32	0.5312
18	0.6250	0.5889	0.5528	37-64	0.5781
3/4-10	0.7500	0.6850	0.6201	21-32	0.6562
16	0.7500	0.7094	0.6688	11-16	0.6875
7/8- 9	0.8750	0.8029	0.7307	49-64	0.7656
14	0.8750	0.8286	0.7822	13-16	0.8125
1- 8	1.0000	0.9188	0.8376	7-8	0.8750
14	1.0000	0.9536	0.9072	15-16	0.9375
1 1/8- 7	1.1250	1.0322	0.9394	63-64	0.9844
12	1.1250	1.0709	1.0168	1 3-64	1.0469
1 1/4- 7	1.2500	1.1572	1.0644	1 7-64	1.1094
12	1.2500	1.1959	1.1418	1 11-64	1.1719
1 3/8- 6	1.3750	1.2667	1.1585	1 7-32	1.2187
12	1.3750	1.3209	1.2668	1 19-64	1.2969
1 1/2- 6	1.5000	1.3917	1.2835	1 11-32	1.3437
12	1.5000	1.4459	1.3918	1 27-64	1.4219
1 3/4- 5	1.7500	1.6201	1.4902	1 9-16	1.5625
2 - 4 1/2	2.0000	1.8557	1.7113	1 25-32	1.7812
2 1/4- 4 1/2	2.2500	2.1057	1.9613	2 1-32	2.0312
2 1/2- 4	2.5000	2.3376	2.1752	2 1-4	2.2500
2 3/4- 4	2.7500	2.5876	2.4252	2 1-2	2.5000
3- 4	3.0000	2.8376	2.6752	2 3-4	2.7500
3 1/4- 4	3.2500	3.0876	2.9252	3	3.0000
3 1/2- 4	3.5000	3.3376	3.1752	3 1-4	3.2500
3 3/4- 4	3.7500	3.5876	3.4252	3 1-2	3.5000
4- 4	4.0000	3.8376	3.6752	3 3-4	3.7500

REASONS FOR FINER PITCHES (NATIONAL FINE)

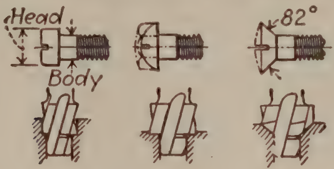
Threads in automobile work are cut in hard tough materials and do not require to be so coarse as threads cut in cast iron. A screw or bolt of a given size and of finer pitch has greater minor diameter and consequently greater strength than a coarse-pitch screw of same size. A fine-pitch screw or nut may be set up tighter and does not shake loose so readily as one of coarse pitch.

TABLE 18.—COUNTERBORE SIZES FOR MACHINE SCREWS



Screw sizes	No. thds. per in. NC	No. thds. per in. NF	Fillister head mach. screw head & body: Bore for head	Fillister head mach. screw head & body: Pilot for body	Round or hex. head mach. screw head & body: Bore for head	Round or hex. head mach. screw head & body: Pilot for body	Flat or oval head mach. screw head & body: Bore for head	Flat or oval head mach. screw head & body: Pilot for body	Tap drills NC	Tap drills NF	Decimal equivalents of tap-drill sizes
0		80	0.096	0.060	0.125	0.060	0.125	0.060		3/64	0.0469
1	64		0.118	0.073	0.156	0.073	0.156	0.073	53		0.0595
		72								53	0.0595
2	56		0.140	0.086	0.187	0.086	0.187	0.086	50		0.0700
		64								50	0.0700
3	48		0.161	0.099	0.203	0.099	0.218	0.099	47		0.0785
		56								45	0.0820
4	40		0.183	0.112	0.234	0.112	0.250	0.112	43		0.0890
		48								42	0.0935
5	40		0.205	0.125	0.250	0.125	0.281	0.125	38		0.1015
		44								37	0.1040
6	32		0.227	0.138	0.281	0.138	0.312	.138	36		0.1065
		40								33	0.1130
8	32		0.270	0.164	0.328	0.164	0.375	0.164	29		0.1360
		36								29	0.1360
10	24		0.313	0.190	0.375	0.190	0.437	0.190	25		0.1495
		32								21	C.1590
12	24		0.357	0.216	0.437	0.216	0.500	0.216	16		0.1770
		28								14	0.1820
1/4	20		0.414	0.250	0.500	0.250	0.562	0.250	7		0.2010
		28								3	0.2130
5/16	18		0.519	0.312	0.625	0.312	0.656	0.312	F		0.2570
		24								I	0.2720
3/8	16		0.622	0.375	0.750	0.375	0.781	0.375	5/16		0.3125
		24								Q	0.3320
7/16	14		0.719	0.437	0.875	0.437	0.937	0.437	U		0.3680
		20								25/64	0.3906
1/2	13		0.820	0.500	1.000	0.500	1.062	0.500	27/64		0.4219
		20								29/64	0.4531

TABLE 19.—COUNTERBORE SIZES FOR CAP SCREWS



Major diameter	No. of threads per inch	Fillister head cap screw head & body		Button or hex. head cap screw head & body		Flat or oval head cap screw head & body		Tap drill	Decimal equivalent of tap drill
		Bore for head	Pilot for body	Bore for head	Pilot for body	Bore for head	Pilot for body		
1/4	20	0.375	0.250	0.500	0.250	0.562	0.250	7	0.2010
5/16	18	0.437	0.312	0.625	0.312	0.656	0.312	F	0.2570
3/8	16	0.562	0.375	0.687	0.375	0.781	0.375	5/16	0.3125
7/16	14	0.625	0.437	0.813	0.437	0.875	0.437	U	0.3680
1/2	13	0.750	0.500	0.875	0.500	0.968	0.500	27/64	0.4218
9/16	12	0.812	0.562	1.000	0.562	1.062	0.562	31/64	0.4844
5/8	11	0.875	0.625	1.062	0.625	1.187	0.625	17/32	0.5312
3/4	10	1.000	0.750	1.312	0.750	1.437	0.750	21/32	0.6562
7/8	9	1.125	0.875	1.375	0.875	.....	.....	49/64	0.7656
1	8	1.312	1.000	1.500	1.000	.....	.....	7/8	0.8750

Table 20.—Decimal Equivalents of the Number and Letter Sizes of Twist Drills

No.	Size in decimals	No.	Size in decimals	No.	Size in decimals	No.	Size in decimals
1	.2280	21	.1590	41	.0960	61	.0390
2	.2210	22	.1570	42	.0935	62	.0380
3	.2130	23	.1540	43	.0890	63	.0370
4	.2090	24	.1520	44	.0860	64	.0360
5	.2055	25	.1495	45	.0820	65	.0350
6	.2040	26	.1470	46	.0810	66	.0330
7	.2010	27	.1440	47	.0785	67	.0320
8	.1990	28	.1405	48	.0760	68	.0310
9	.1960	29	.1360	49	.0730	69	.02925
10	.1935	30	.1285	50	.0700	70	.0280
11	.1910	31	.1200	51	.0670	71	.0260
12	.1890	32	.1160	52	.0635	72	.0250
13	.1850	33	.1130	53	.0595	73	.0240
14	.1820	34	.1110	54	.0550	74	.0225
15	.1800	35	.1100	55	.0520	75	.0210
16	.1770	36	.1065	56	.0465	76	.0200
17	.1730	37	.1040	57	.0430	77	.0180
18	.1695	38	.1015	58	.0420	78	.0160
19	.1660	39	.0995	59	.0410	79	.0145
20	.1610	40	.0980	60	.0400	80	.0135

Letter Sizes of Drills

Letter	Size in decimals	Letter	Size in decimals
A $\frac{15}{64}$	.234	N	.302
B	.238	O $\frac{5}{16}$	.316
C	.242	P $\frac{21}{64}$	.323
D	.246	Q	.332
E $\frac{1}{4}$	.250	R $\frac{11}{32}$	.339
F	.257	S	.348
G	.261	T $\frac{23}{64}$	.358
H $\frac{17}{64}$	.266	U	.368
I	.272	V $\frac{3}{8}$	.377
J	.277	W $\frac{25}{64}$	.386
K $\frac{9}{32}$	.281	X	.397
L	.290	Y $\frac{13}{32}$	.404
M $\frac{19}{64}$	.295	Z	.413

INDEX

[1] NOTE: Many planer and shaper operations are practically alike, see pp. 161 and 187 and memoranda, p. 187. The term "planing" is used in both planer and shaper work.

Date Due

709	Jul [illegible]'41		
1399	Aug 8'41		
1399	Aug 2[illegible]'41		
1399	Oct 18'41		
1399	Nov 1'41		
1292	Dec 6'41		
1548	Feb 24'4[illegible]		
1015	Oct 9'43		
521	Dec 6'44		
95	Oct [illegible]'54		
—	Dec 17'54		
30	Dec 17'65		
Morony	Apr 30'66		
30	Aug 30'67		
30	Nov 23'68		

HUNTTING—1320